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The Franklin Institute
Devoted to Science and the Mechanic Arts

Vol. 205 FEBRUARY, 1928 No. 2

SOME EXPERIMENTAL DIFFICULTIES WITH THE ELECTROMAGNETIC THEORY OF RADIATION.

BY

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DURING the last few years it has become increasingly evident that the classical electromagnetic theory of radiation is incapable of accounting for certain large classes of phenomena, especially those concerned with the interaction between radiation and matter. It is not that we question the wave character of light—the striking successes of this conception in explaining polarization and interference of light can leave no doubt that radiation has the characteristics of waves; but it is equally true that certain other properties of radiation are not easily interpreted in terms of waves. The power of the electromagnetic theory as applied to a great variety of problems of radiation is too well known to require emphasis. It is, however, only by acquainting ourselves with the failures of this powerful theory that we can hope to develop a more complete theory of radiation which will describe the facts as we know them.

The more serious difficulties which present themselves in connection with the theory that radiation consists of electromagnetic waves, propagated through space in accord with the demands of Maxwell's equations, may be classified conveniently under four heads:

(1) How are the waves produced? The classical electro-

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dynamics requires as a source of an electromagnetic wave an oscillator of the same frequency as that of the waves it radiates. Our studies of spectra, however, make it appear impossible that an atom should contain oscillators of the same frequencies as the emitted rays.

(2) The photo-electric effect. This phenomenon is wholly anomalous when viewed from the standpoint of waves.

(3) The scattering of X-rays, and the recoil electrons, phenomena in which we find gradually increasing departures from the predictions of the classical wave theory as the frequency increases.

(4) Experiments on individual interactions between quanta of radiation and electrons. If the results of the experiments of this type are reliable, they seem to show definitely that individual quanta of radiation, of energy $h\nu$, proceed in definite directions.

The Photon Hypothesis.—In order to exhibit more clearly the difficulties with the classical theory of radiation, it will be helpful to keep in mind the suggestion that light consists of corpuscles. We need not think of these two views as necessarily alternative. It may well be that the two conceptions are complementary. Perhaps the corpuscle is related to the wave in somewhat the same manner that the molecule is related to matter in bulk; or there may be a guiding wave which directs the corpuscles which carry the energy. In any case, the phenomena which we have just mentioned suggest the hypothesis that radiation is divisible into units possessing energy $h\nu$, and which proceed in definite directions with momentum $h\nu/c$. This is obviously similar to Newton's old conception of light corpuscles. It was revived in its present form by Einstein, it was defended under the name of the "Neutron Theory" by Sir William Bragg, and has been given new life by the recent discoveries associated with the scattering of X-rays.

In referring to this unit of radiation I shall use the name "photon," suggested recently by G. N. Lewis.[1] This word avoids any implication regarding the nature of the unit, as contained for example in the name "needle ray." As compared with the terms "radiation quantum" and "light quant," this name has the advantages of brevity and of avoiding any implied

[1] G. N. Lewis, *Nature*, Dec. 18, 1926.

dependence upon the much more general quantum mechanics or quantum theory of atomic structure.

Virtual Radiation.—Another conception of the nature of radiation which it will be desirable to compare with the experiments is Bohr, Kramers and Slater's important theory of virtual radiation.[2] According to this theory, an atom in an excited state is continually emitting virtual radiation, to which no energy characteristics are to be ascribed. The normal atoms have associated with them virtual oscillators, of the frequencies corresponding to jumps of the atom to all of the stationary states of higher energy. The virtual radiation may be thought of as being absorbed by these virtual oscillators, and any atom which has a virtual oscillator absorbing this virtual radiation has a certain probability of jumping suddenly to the higher state of energy corresponding to the frequency of the particular virtual oscillator. On the average, if the radiation is completely absorbed, the number of such jumps to levels of higher energy is equal to the number of emitting atoms which pass from higher to lower states. But there is no direct connection between the falling of one atom from a higher to a lower state and a corresponding rise of a second atom from a lower to a higher state. Thus on this view the energy of the emitting atoms and of the absorbing atoms is only statistically conserved.

THE EMISSION OF RADIATION.

When we trace a sound to its origin, we find it coming from an oscillator vibrating with the frequency of the sound itself. The same is true of electric waves, such as radio waves, where the source of the radiation is a stream of electrons oscillating back and forth in a wire. But when we trace a light ray or an X-ray back to its origin, we fail to find any oscillator which has the same frequency as the ray itself. The more complete our knowledge becomes of the origin of spectrum lines, the more clearly we see that if we are to assign any frequencies to the electrons within the atoms, these frequencies are not the frequencies of the emitted rays, but are the frequencies associated with the stationary states of the atom. This result cannot be reconciled with the electromagnetic theory of radiation, nor has

[2] N. Bohr, H. A. Kramers and J. C. Slater, *Phil. Mag.*, **47**, 785 (1924); *Zeits. f. Phys.*, **24**, 69 (1924).

any mechanism been suggested whereby radiation of one frequency can be excited by an oscillator of another frequency. The wave theory of radiation is thus powerless to suggest how the waves originate.

The origin of the radiation is considerably simpler when we consider it from the photon viewpoint. We find that an atom changes from a stationary state of one energy to a state of less energy, and associated with this change radiation is emitted. What is simpler than to suppose that the energy lost by the atom is radiated away as a single photon? It is on this view unnecessary to say anything regarding the frequency of the radiation. We are concerned only with the energy of the photon, its direction of emission, and its state of polarization.

The problem of the emission of radiation takes an especially interesting form when we consider the production of the continuous X-ray spectrum.[3] Experiment shows that both the intensity and the average frequency of the X-rays emitted at angles less than 90 degrees with the cathode-ray stream are greater than at angles greater than 90 degrees. This is just what we should expect due to the Doppler effect if the X-rays are emitted by a radiator moving in the direction of the cathode rays. In order to account for the observed dissymmetry between the rays in the forward and backward directions, the particles emitting the radiation must be moving with a speed of the order of 25 per cent. that of light. This means that the emitting particles must be free electrons, since it would require an impossibly large energy to set an atom into motion with such a speed.

But it will be recalled that the continuous X-ray spectrum has a sharp upper limit. Such a sharp limit is, however, possible on the wave theory only in case the rays come in trains of waves of considerable length, so that the interference between the waves in different parts of the train can be complete at small glancing angles of reflection from the crystal. This implies that the oscillator which emits the rays must vibrate back and forth with constant frequency a large number of times while the ray is being emitted. Such an oscillation might be imagined for an electron within an atom; but it is impossible for an electron moving

[3] The difficulty here discussed was first emphasized by D. L. Webster, *Phys. Rev.*, 13, 303 (1919).

through an irregular assemblage of atoms with a speed comparable with that of light.

Thus the Doppler effect in the primary X-rays demands that the rays shall be emitted by rapidly moving electrons, while the sharp limit to the continuous spectrum requires that the rays be emitted by an electron bound within an atom.

The only possible escape from this dilemma on the wave theory is to suppose that the electron is itself capable of internal oscillation of such a character as to emit radiation. This would, however, introduce an undesirable complexity into our conception of the electron, and would ascribe the continuous X-rays to an origin entirely different from that of other known sources of radiation.

Here again the photon theory affords a simple solution. It is a consequence of Ehrenfests's adiabatic principle that photons emitted by a moving radiator will show the same Doppler effect, with regard to both frequency and intensity, as does a beam of waves.[4] But if we suppose that photons are radiated by the moving cathode electrons, the energy of each photon will be the energy lost by the electron, and the limit of the X-ray spectrum is necessarily reached when the energy of the photon is equal to the initial energy of the electron, *i.e.*, $h\nu = eV$. In this case, if we consider the initial state as an electron approaching an atom with large kinetic energy and the final state as the electron leaving the atom with a smaller kinetic energy, we see that the emission of the continuous X-ray spectrum is the same kind of event as the emission of any other type of radiation.

Absorption of Radiation.—According to the photon theory, absorption occurs when a photon meets an atom and imparts its energy to the atom. The atom is thereby raised to a stationary state of higher energy—precisely the reverse of the emission process.

On the wave theory, absorption is necessarily a continuous process, if we admit the conservation of energy, since on no part of the wave front is there enough energy available to change the atom suddenly from a state of low energy to a state of higher energy. What evidence we have is, however, strongly against the atom having for any considerable length of time an energy intermediate between two stationary states; and if such inter-

[4] *Cf., e.g.*, A. H. Compton, *Phys. Rev.*, **21**, 483 (1923).

mediate states cannot exist, the gradual absorption of radiation is not possible. Thus the absorption of energy from waves is irreconcilable with the conception of stationary states.

We have seen that on the theory of virtual radiation the energy of the emitting atoms and of the absorbing atoms is only statistically conserved. There is according to this view therefore no difficulty with supposing that the absorbing atom suddenly jumps to a higher level of energy, even though it has not received from the radiation as much energy as is necessary to make the jump. It is thus possible through virtual oscillators and virtual radiation to reconcile the wave theory of radiation with the sudden absorption of energy, and hence to retain the idea of stationary states.

THE PHOTO-ELECTRIC EFFECT.

It is well known that the photon hypothesis was introduced by Einstein to account for the photo-electric effect.[5] The assumption that light consists of discrete units which can be absorbed by atoms only as units, each giving rise to a photo-electron, accounted at once for the fact that the number of photo-electrons is proportional to the intensity of the light; and the assumption that the energy of the light unit is equal to $h\nu$, where h is Planck's constant, made it possible to predict the kinetic energy with which the photo-electrons should be ejected, as expressed by Einstein's well-known photo-electric equation,

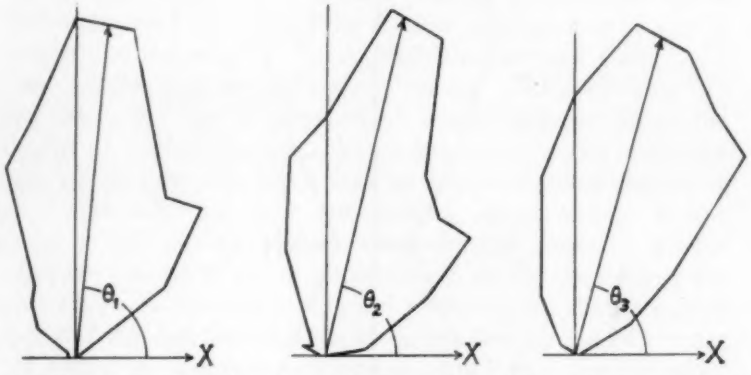
$$mc^2\left(\frac{1}{\sqrt{1-\beta^2}}-1\right)=h\nu-w_p. \qquad (1)$$

Seven years elapsed before experiments by Richardson and Compton[6] and by Hughes[7] showed that the energy of the emitted electrons was indeed proportional to the frequency less a constant, and that the factor of proportionality was close to the value of h calculated from Planck's radiation formula. Millikan's more recent precision photo-electric experiments with the alkali metals[8] confirmed the identity of the constant h in the photo-electric equation with that in Planck's radiation formula. De Broglie's beautiful experiments[9] with the magnetic spectrograph

[5] A. Einstein, *Ann. d. Phys.*, **17**, 145 (1905).
[6] O. W. Richardson and K. T. Compton, *Phil. Mag.*, **24**, 575 (1912).
[7] A. L. Hughes, *Phil. Trans.*, **A. 213**, 205 (1912).
[8] R. A. Millikan, *Phys. Rev.*, **7**, 355 (1916).
[9] M. de Broglie, *Jour. de Phys.*, **2**, 265 (1921).

showed that in the region of X-ray frequencies the same equation holds, if only we interpret the work function w_p as the work required to remove the electron from the Pth energy level of the atom. Thibaud has made use of this result [10] in comparing the velocities of the photo-electrons ejected by γ-rays from different elements, and has thus shown that the photo-electric equation (1) holds with precision even for β-rays of the highest speed. Thus from light of frequency so low that it is barely able to eject photo-electrons from metals to γ-rays that eject photo-

FIG. 1.



Longitudinal distribution of photo-electrons for X-rays of three different effective wave-lengths, according to Auger.

electrons with a speed almost as great as that of light, the photon theory expresses accurately the speed of the photo-electrons.

The direction in which the photo-electrons are emitted is no less instructive than is the velocity. Experiments using the cloud expansion method, performed by C. T. R. Wilson [11] and others,[12] have shown that the most probable direction in which the photo-electron is ejected from an atom is nearly the direction of the electric vector of the incident wave, but with an appreciable forward component to its motion. There is, however, a very considerable variation in the direction of emission. For example,

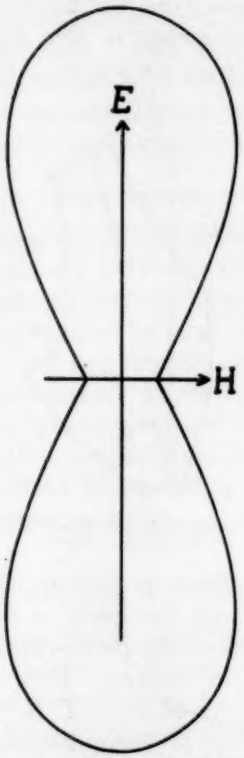
[10] J. Thibaud, *C. R.*, **179**, pp. 165, 1053, and 1322 (1924).

[11] C. T. R. Wilson, *Proc. Roy. Soc.*, **A. 104**, 1 (1923).

[12] A. H. Compton, *Bull. Natl. Res. Coun. No. 20*, p. 25 (1922); F. W. Bubb, *Phys. Rev.*, **23**, 137 (1924); P. Auger, *C. R.*, **178**, 1535 (1924); D. H. Loughridge, *Phys. Rev.*, **26**, 697 (1925); F. Kirchner, *Zeits. f. Phys.*, **27**, 385 (1926).

if we plot the number of photo-electrons ejected at different angles with the primary beam we find, according to Auger, the distribution shown in Fig. 1. Each of these curves, taken at a different potential, represents the distribution of about 200 photo-electron tracks. It will be seen that as the potential on the X-ray

FIG. 2.



Lateral distribution of photo-electrons for incompletely polarized X-rays, according to Bubb.

tube increases, the average forward component of the photo-electron's motion also increases.

When polarized X-rays are used, there is a strong preponderance of the photo-electrons in or near the plane including the electric vector of the incident rays. Thus Fig. 2 shows the distribution found by Bubb of the direction of the photo-electrons ejected from moist air when traversed by X-rays that have been polarized by scattering at right angles from a block of paraffin.

Because of multiple scattering in the paraffin, the scattered rays are not completely polarized, and this is probably sufficient to account for the fact that some photo-electrons appear to start at right angles with the electric vector. This effect with X-rays is doubtless similar in character to the selective photo-electric effect discovered many years ago by Pohl and Pringsheim, in which the number of electrons ejected by light from the liquid surface of sodium-potassium alloy is greater when the electric vector is in a plane perpendicular to the surface than when parallel to the surface.

Recent experiments have shown that the direction in which the photo-electrons are ejected by X-rays is at least very nearly independent of the material from which the electrons come.[13]

Can Electromagnetic Waves Produce Photo-electrons?—Before discussing the production of photo-electrons from the standpoint of radiation quanta, let us see what success meets the attempt to account for them on the basis of electromagnetic waves. The fact that they are emitted approximately in the direction of the electric vector would suggest that the photo-electrons are ejected by the direct action of the electric field of the incident rays. If this were the case, however, we should expect the speed of the ejected electrons to be greater for greater intensity of radiation, whereas experiment shows that for the same wave-length intense sunlight ejects an electron no faster than does the feeble light from a star. Furthermore, the energy available from the electromagnetic wave is wholly inadequate. Thus in a recent experiment performed by Joffe and Dobronsawov,[14] X-rays were produced by the impact on a target of 10^4 to 10^5 electrons per second. Since on the electromagnetic theory an X-ray pulse is of the order of 10^3 waves in length or 10^{-16} seconds in duration, the X-ray pulses must have followed each other at widely separated intervals. It was found, however, that photo-electrons were occasionally ejected from a bismuth particle which subtended a solid angle not greater than 10^{-5}. It is clearly impossible that all the energy of an X-ray pulse which has spread out in a spherical wave should spend itself on this bismuth particle. Thus on the wave theory the ejection of the photo-

[13] E. A. Owen, *Proc. Phys. Soc.*, **30**, 133 (1918); Auger, Kirchner, Loughridge, *loc. cit.*

[14] A. Joffe and N. Dobronsawov, *Zeits. f. Phys.*, **34**, 889 (1925).

electron, which has almost as much energy as the original cathode electron, could not have been accomplished by a single pulse. It cannot therefore be the direct action of the electric vector of the wave, taken in the usual sense, which has ejected the electron.

We may assume, on the other hand, that the energy is gradually absorbed in the bismuth particle of Joffe's experiment until an amount $h\nu$ has accumulated, which is then spent in ejecting the photo-electron. We have already called attention to the fact that this gradual absorption hypothesis implies the existence of stationary states in the atom having infinitesimal gradations of energy, whereas the evidence is very strong that atoms cannot endure except in certain definitely defined stationary states. But new difficulties also arise. Why do the photo-electrons tend to start in the direction of the electric field of the incident wave? If we suppose that it is the gradual absorption of energy from a wave which liberates the electron, why does there exist a tendency for the electron to start with a large component of its motion in a forward direction? The forward impulse due to the radiation pressure as the energy is gradually absorbed will be transferred to the atom and not left with absorbing electron. The accumulation hypothesis is thus difficult to defend.

Photons and Photo-electrons.—On the photon theory it is possible to account in a simple manner for most of the properties of the photo-electrons. We have seen how Einstein was able to predict accurately the velocity of the photo-electrons, assuming only that energy is conserved when a photon acts on an electron. In order to account for the direction of emission we must ascribe to the photon some of the properties of an electromagnetic pulse. Bubb introduced the suggestion [15] that we ascribe to the photon a vector property similar to the electric vector of an electromagnetic wave, so that when the photon traverses an atom the electrons and the nucleus receive impulses in opposite directions perpendicular to the direction of propagation. Associated with this electric vector, we should also expect to find a magnetic vector. Thus if an electron is set in motion by the electric vector of the photon at right angles to the direction of propagation, the magnetic vector of the photon will act on the moving electron in the direction of propagation. This is strictly analogous to the radiation pressure exerted by an electromagnetic wave on an elec-

[15] F. W. Bubb, *Phys. Rev.*, **23**, 137 (1924).

tron which it traverses, and means that the forward momentum of the absorbed photon is transferred to the photo-electron.

In the simplest case, where we neglect the initial momentum of the electron in its orbital motion in the atom, the angle between the direction of the incident ray and the direction of ejection is found from these assumptions to be,

$$\theta = \tan^{-1} \sqrt{2/\alpha}, \qquad (2)$$

where $\alpha = \gamma/\lambda$, and $\gamma = h/mc = 0.0242$ A. The quantity α is small compared with unity, except for very hard X-rays and γ-rays. Thus for light, equation (2) predicts the expulsion of photo-electrons at nearly 90 degrees. This is in accord with the rather uncertain data which have been obtained with visible and ultra-violet light.[16]

The only really significant test of this result is in its application to X-ray photo-electrons. In Fig. 1 are drawn the lines θ_1, θ_2 and θ_3 for the three curves, at the angles calculated by Auger from equation (2). It will be seen that they fall very satisfactorily in the direction of maximum emission of the photo-electrons. Similar results have been obtained by other investigators.[17] This may be taken as proof that a photon imparts not only its energy, but also its momentum to the photo-electrons.[18]

If the angular momentum of the atomic system from which the photo-electron is ejected is to be conserved when acted upon by the radiation, the electron cannot be ejected exactly in the direction of θ, but must receive an impulse in a direction determined by the position of the electron in the atom at the instant

[16] *Cf.* A. Partsch and W. Hallwachs, *Ann. d. Phys.*, **41**, 247 (1913).

[17] W. Bothe, *Zeits. f. Phys.*, **26**, 59 (1925); F. Kirchner, *Zeits. f. Phys.*, **27**, 385 (1926).

[18] Since this was written, experiments by Loughridge (*Phys. Rev.*, **30**, 1927) have been published which show a forward component to the photo-electron's motion which seems to be greater than that predicted by equation (2). Williams, in experiments as yet unpublished, finds that the forward component is almost twice as great as that predicted by this theory. These results indicate that the mechanism of interaction between the photon and the atom must be more complex than here postulated. The fact that the forward momentum of the photo-electron is found to be of the same order of magnitude as that of the incident photon, however, suggests that the momentum of the photon is acquired by the photo-electron, while an additional forward impulse is imparted by the atom. Thus these more recent experiments also support the view that the photo-electron acquires both the energy and the momentum of the photon.

it is traversed by the photon.[19] Thus we should probably consider the electric vector of the X-ray wave as defining merely the most probable direction in which the impulse should be imparted to the electron. This is doubtless the chief reason why the photo-electrons are emitted over a wide range of angles instead of in a definite direction, as would be suggested by the calculation just outlined.

It will readily be seen that if the time during which the photon exerts a force on the electron is comparable with the natural period of the electron in the atom, the impulse imparted to the electron will be transferred in part to the positive nucleus about which the electron is moving. The fact that the photo-electrons receive the momentum of the incident photon means that no appreciable part of the photon's momentum is spent on the remainder of the atom. This can only be the case if the time of action of the photon on the electron is short compared with the time of revolution of the electron in its orbit. Such a short duration of interaction is a natural consequence of the photon conception of radiation, but is quite contrary to the consequences of the electromagnetic theory.

The Photo-electric Effect and Virtual Radiation.—It is to be noted that none of these properties of the photo-electron is inconsistent with the virtual radiation theory of Bohr, Kramers and Slater. The difficulties which applied to the classical wave theory do not apply here, since the energy and momentum are conserved only statistically. There is nothing in this theory, however, which would enable us to predict anything regarding the motion of the photo-electrons. The degree of success that has attended the application of the photon hypothesis to the motion of these electrons has come directly from the application of the conservation principles to the individual action of a photon on an electron. The power of these principles as applied to this case is surprising if the assumption is correct that they are only statistically valid.

PHENOMENA ASSOCIATED WITH THE SCATTERING OF X-RAYS.

As is now well known, there is a group of phenomena associated with the scattering of X-rays for which the classical wave theory of radiation fails to account. These phenomena may be

[19] *Cf.* A. H. Compton, *Phys. Rev.*, 1928.

considered under the heads of: (1) The change of wave-length of X-rays due to scattering, (2) the intensity of scattered X-rays, and (3) the recoil electrons.

The earliest experiments on secondary X-rays and γ-rays showed a difference in the penetrating power of the primary and the secondary rays. In the case of X-rays, Barkla and his collaborators showed that the secondary rays from the heavy elements consisted largely of fluorescent radiations characteristic of the radiator, and that it was the presence of these softer rays which was chiefly responsible for the greater absorption of the secondary rays. When later experiments [20] showed a measurable difference in penetration even for light elements such as carbon, from which no fluorescent K or L radiation appears, it was natural to ascribe [21] this difference to a new type of fluorescent radiation, similar to the K and L types, but of shorter wave-length. Careful absorption measurements [22] failed, however, to reveal any critical absorption limit for these assumed "J" radiations similar to those corresponding to the K and L radiations. Moreover, direct spectroscopic observations [23] failed to reveal the existence of any spectrum lines under conditions for which the supposed J-rays should appear. It thus became evident that the softening of the secondary X-rays from the lighter elements was due to a different kind of process than the softening of the secondary rays from heavy elements where fluorescent X-rays are present.

A series of skilfully devised absorption experiments performed by J. A. Gray [24] showed, on the other hand, that both in the case of γ-rays and in that of X-rays an increase in wave-length accompanies the scattering of the rays of light elements.

It was at this stage that the first spectroscopic investigations of the secondary X-rays from light elements were made.[25]

[20] C. A. Sadler and P. Mesham, *Phil. Mag.*, **24**, 138 (1912); J. Laub, *Ann. d. Phys.*, **46**, 785 (1915).

[21] Barkla and White, *Phil. Mag.*, **34**, 270 (1917); J. Laub, *Ann. d. Phys.*, **46**, 785 (1915), *et al.*

[22] *E.g.*, Richtmyer and Grant, *Phys. Rev.*, **15**, 547 (1920).

[23] E. G. Duane and Shimizu, *Phys. Rev.*, **13**, 288 (1919); **14**, 389 (1919).

[24] J. A. Gray, *Phil. Mag.*, **26**, 611 (1913); JOUR. FRANK. INST., Nov., 1920, p. 643.

[25] A. H. Compton, *Bull. Natl. Res. Coun. No. 20* (1922); *Phys. Rev.*, **22**, 409 (1923).

According to the usual electron theory of scattering it is obvious that the scattered rays will be of the same frequency as the forced oscillations of the electrons which emit them, and hence will be identical in frequency with the primary waves which set the electrons in motion. Instead of showing scattered rays of the same wave-length as the primary rays, however, these spectra revealed lines in the secondary rays corresponding to those in the primary beam, but with each line displaced slightly toward the longer wave-lengths.

This result might have been predicted from Gray's absorption measurements; but the spectrum measurements had the advantage of affording a quantitative measurement of the change in wave-length, which gave a basis for its theoretical interpretation.

The spectroscopic experiments which have shown this change in wave-length are too well known [26] to require discussion. The interpretation of the wave-length change in terms of photons being deflected by individual electrons and imparting a part of their energy to the scattering electrons is also very familiar. For purposes of discussion, however, let us recall that when we consider the interaction of a single photon with a single electron the principles of the conservation of energy and momentum lead us [27] to the result that the change in wave-length of the deflected photon is

$$\delta\lambda = \frac{h}{mc}(1 - \cos\varphi), \tag{3}$$

where φ is the angle through which the photon is deflected. The electron at the same time recoils from the photon at an angle of θ given by,

$$\cot\theta = -(1 + x)\tan\frac{1}{2}\varphi; \tag{4}$$

and the kinetic energy of the recoiling electron is,

$$E_{\text{kin}} = h\nu\frac{2\alpha\cos^2\theta}{(1+\alpha)^2 - \alpha^2\cos^2\theta}. \tag{5}$$

The experiments show in the spectrum of the scattered rays two lines corresponding to each line of the primary ray. One

[26] *Cf., e.g.*, A. H. Compton, *Phys. Rev.*, **22**, 409 (1923); P. A. Ross, *Prov. Nat. Acad.*, **10**, 304 (1924).

[27] A. H. Compton, *Phys. Rev.*, **22**, 483 (1923); P. Debye, *Phys. Zeits.*, **24**, 161 (1923).

of these lines is of precisely the same wave-length as the primary ray, and the second line, though somewhat broadened, has its centre of gravity displaced by the amount predicted by equation (3). According to experiments by Kallman and Mark [28] and by Sharp,[29] this agreement between the theoretical and the observed shift is precise to within a small fraction of 1 per cent.

The Recoil Electrons.—From the quantitative agreement between the theoretical and the observed wave-lengths of the scattered rays, the recoil electrons predicted by the photon theory of scattering were looked for with some confidence. When this theory was proposed, there was no direct evidence for the existence of such electrons, though indirect evidence suggested that the secondary beta-rays ejected from matter by hard γ-rays are mostly of this type. Within a few months of their prediction, however, C. T. R. Wilson [30] and W. Bothe [31] independently announced their discovery. The recoil electrons show as short tracks, pointed in the direction of the primary X-ray beam, mixed among the much longer tracks due to the photo-electrons ejected by the X-rays.

Perhaps the most convincing reason for associating these short tracks with the scattered X-rays comes from a study of their number. Each photo-electron in a cloud photograph represents a quantum of truly absorbed X-ray energy. If the short tracks are due to recoil electrons, each one should represent the scattering of a photon. Thus the ratio N_r/N_p of the number of short tracks to the number of long tracks should be the same as the ratio σ/t of the scattered to the truly absorbed energy when the X-rays pass through air. The latter ratio is known from absorption measurements, and the former ratio can be determined by counting the tracks on the photographs. The satisfactory agreement between the two ratios [32] for X-rays of different wave-lengths means that on the average there is about one quantum of energy scattered for each short track that is produced.

This result is in itself contrary to the predictions of the classical wave theory, since on this basis all the energy spent on

[28] H. Kallman and H. Mark, *Naturwiss.*, **13**, 297 (1925).

[29] H. M. Sharp, *Phys. Rev.*, **26**, 691 (1925).

[30] C. T. R. Wilson, *Proc. Roy. Soc.*, **104**, 1 (1923).

[31] W. Bothe, *Zeits. f. Phys.*, **16**, 319 (1923).

[32] A. H. Compton and A. W. Simon, *Phys. Rev.*, **25**, 306 (1925); J. M. Nuttall and E. J. Williams, *Manchester Memoirs*, **70**, 1 (1926).

a free electron (except the insignificant effect of radiation pressure) should reappear as scattered X-rays. In these experiments, on the contrary, 5 or 10 per cent. as much energy appears in the motion of the recoil electrons as appears in the scattered X-rays.

That these short tracks associated with the scattered X-rays correspond to the recoil electrons predicted by the photon theory of scattering becomes clear from a study of their energies. The energy of the electron which produces a track can be calculated from the range of the track. The ranges of tracks which start in different directions have been studied,[33] using primary X-rays of different wave-lengths, with the result that equation (5) has been satisfactorily verified.

In view of the fact that electrons of this type were unknown at the time the photon theory of scattering was presented, their existence, and the close agreement with the predictions as to their number, direction and velocity, supply strong evidence in favor of the fundamental hypotheses of the theory.

Interpretation of These Experiments.—It is impossible to account for scattered rays of altered frequency, and for the existence of the recoil electrons, if we assume that X-rays consist of electromagnetic waves in the usual sense. Yet some progress has been made on the basis of semi-classical theories. It is an interesting fact that the wave-length of the scattered ray according to equation (3) varies with the angle just as one would expect from a Doppler effect if the rays are scattered from an electron moving in the direction of the primary beam. Moreover, the velocity that must be assigned to the electron in order to give the proper magnitude to the change of wave-length is that which the electron would acquire by radiation pressure if it should absorb a quantum of the incident rays. Several writers[34] have therefore assumed that an electron takes from the incident beam a whole quantum of the incident radiation, and then emits this energy as a spherical wave while moving forward with high velocity.

This conception that the radiation occurs in spherical waves, and that the scattering electron can nevertheless acquire suddenly

[33] Compton and Simon, *loc. cit.*

[34] C. R. Bauer, *C. R.*, **177**, 1211 (1923); C. T. R. Wilson, *Proc. Roy. Soc.*, **104**, 1 (1923); K. Forsterling, *Phys. Zeits.*, **25**, 313 (1924); O. Halpern, *Zeits. f. Phys.*, **30**, 153 (1924).

the impulses from a whole quantum of incident radiation is inconsistent with the principle of energy conservation. But there is the more serious experimental difficulty that this theory predicts recoil electrons all moving in the same direction and with the same velocity. The experiments show, on the other hand, a variety of directions and velocities, with the velocity and direction correlated as demanded by the photon hypothesis. Moreover, the maximum range of the recoil electrons, though in agreement with the predictions of the photon theory, is found to be about four times as great as that predicted by this semi-classical theory.

There is nothing in these experiments, as far as we have described them, which is inconsistent with the idea of virtual oscillators continually scattering virtual radiation. In order to account for the change of wave-length on this view, Bohr, Kramers and Slater assumed that the virtual oscillators scatter as if moving in the direction of the primary beam, accounting for the change of wave-length as a Doppler effect. They then supposed that occasionally an electron, under the stimulation of the primary virtual rays, will suddenly move forward with a momentum large compared with the impulse received from the radiation pressure. Though we have seen that not all of the recoil electrons move directly forward, but in a variety of different directions, the theory could easily be extended to include the type of motion that is actually observed.

The only objection that one can raise against this virtual radiation theory in connection with the scattering phenomena as viewed on a large scale, is that it is difficult to see how such a theory could by itself predict the change of wave-length and the motion of the recoil electrons. These phenomena are directly predictable if the conservation of energy and momentum are assumed to apply to the individual actions of radiation on electrons; but this is precisely where the virtual radiation theory denies the validity of the conservation principles.

We may conclude that the photon theory predicts quantitatively and in detail the change of wave-length of the scattered X-rays and the characteristics of the recoil electrons. The virtual radiation theory is probably not inconsistent with these experiments, but is incapable of predicting the results. The classical theory, however, is altogether helpless to deal with these phenomena.

The Origin of the Unmodified Line.—The unmodified line is probably due to X-rays which are scattered by electrons so firmly held within the atom that they are not ejected by the impulse from the deflected photons. This view is adequate to account for the major characteristics of the unmodified rays, though as yet no quantitatively satisfactory theory of their origin has been published.[35] It is probable that a detailed account of these rays will involve definite assumptions regarding the nature and the duration of the interaction between a photon and an electron; but it is doubtful whether such investigations will add new evidence as to the existence of the photons themselves.

A similar situation holds regarding the intensity of the scattered X-rays. Historically it was the fact that the classical electromagnetic theory is unable to account for the low intensity of the scattered X-rays which called attention to the importance of the problem of scattering. But the solutions which have been offered by Breit,[36] Dirac [37] and others [38] of this intensity problem as distinguished from that of the change of wave-length, seem to introduce no new concepts regarding the nature of radiation or of the scattering process. Let us therefore turn our attention to the experiments that have been performed on the individual process of interaction between photons and electrons.

INTERACTIONS BETWEEN RADIATION AND SINGLE ELECTRONS.

The most significant of the experiments which show departures from the predictions of the classical wave theory are those that study the action of radiation on individual atoms or on individual electrons. Two methods have been found suitable for performing these experiments, Geiger's point counters, and Wilson's cloud expansion photographs.

(1) *Test for Coincidences with Fluorescent X-rays.*—Bothe has performed an experiment [39] in which fluorescent K radiation

[35] *Cf.*, however, G. E. M. Jauncey, *Phys. Rev.*, **25**, 314 and 723 (1925); G. Wentzel, *Zeits. f. Phys.*, **43**, 14,779 (1927); I. Waller, *Nature*, July 30, 1927. It is possible that the theories of the latter authors may be satisfactory, but they have not yet been stated in a form suitable for quantitative test.

[36] G. Breit, *Phys. Rev.*, **27**, 242 (1926).

[37] P. A. M. Dirac, *Proc. Roy. Soc.*, **A.** (1926).

[38] W. Gordon, *Zeits. f. Phys.*, **40**, 117 (1926); E. Schrodinger, *Ann. d. Phys.*, **82**, 257 (1927); O. Klein, *Zeits. f. Phys.*, **41**, 407 (1927); G. Wentzel, *Zeits. f. Phys.*, **43** (1927).

[39] W. Bothe, *Zeits. f. Phys.*, **37**, 547 (1926).

from a thin copper foil is excited by a beam of incident X-rays. The emitted rays are so feeble that only about five quanta of energy are radiated per second. Two point counters are mounted, one on either side of the copper foil, in each of which an average of one photo-electron is produced and recorded for about twenty quanta radiated by the foil. If we assume that the fluorescent radiation is emitted in quanta of energy, but proceed in spherical waves in all directions, there should thus be about 1 chance in 20 that the recording of a photo-electron in one chamber should be simultaneous with the recording of a photo-electron in the other.

The experiments showed no coincidences other than those which were explicable by such sources as high-speed beta particles which traverse both counting chambers.

This result is in accord with the photon hypothesis. For if a photon of fluorescent radiation produces a beta-ray in one counting chamber it cannot traverse the second chamber. Coincidences should therefore not occur.

According to the virtual radiation hypothesis, however, coincidences should have been observed. For on this view the fluorescent K radiation is emitted by virtual oscillators associated with atoms in which there is a vacancy in the *K* shell. That is, the copper foil can emit fluorescent K radiation only during the short interval of time following the expulsion of a photo-electron from the K shell, until the shell is again occupied by another electron. This time interval is so short (of the order of 10^{-15} sec.) as to be sensibly instantaneous on the scale of Bothe's experiments. Since on this view the virtual fluorescent radiation is emitted in spherical waves, the counting chambers on both sides of the foil should be simultaneously affected, and coincident pulses in the two chambers should frequently occur. The results of the experiment are thus contrary to the predictions of the virtual radiation hypothesis.

(2) *Bothe and Geiger's Coincidence Experiments.*—We have seen that according to Bohr, Kramers and Slater's theory, virtual radiation is being continually scattered by matter traversed by X-rays, but only occasionally is a recoil electron emitted. This is in sharp contrast with the photon theory, according to which a recoil electron appears every time a photon is scattered. A crucial test between the two points of view is afforded by an experiment devised and brilliantly performed by Bothe and

Geiger.[40] X-rays were passed through hydrogen gas, and the resulting recoil electrons and scattered rays were detected by means of two different point counters placed on opposite sides of the column of gas. The chamber for counting the recoil electrons was left open, but a sheet of thin platinum prevented the recoil electrons from entering the chamber for counting the scattered rays. Of course not every photon entering the second counter could be noticed, for its detection depends upon the production of a β-ray. It was found that there were about ten recoil electrons for every scattered photon that recorded itself.

The impulses from the counting chambers were recorded on a moving photographic film. In observations over a total period of over five hours, sixty-six such coincidences were observed. Bothe and Geiger calculate that according to the statistics of the virtual radiation theory the chance was only 1 in 400,000 that so many coincidences should have occurred. This result therefore is in accord with the predictions of the photon theory, but is directly contrary to the statistical view of the scattering process.

(3) *Directional Emission of Scattered X-rays.*—Additional information regarding the nature of scattered X-rays has been obtained by studying the relation between the direction of ejection of the recoil electron and the direction in which the associated photon proceeds. According to the photon theory, we have a definite relation (equation 4) between the angle at which the photon is scattered and the angle at which the recoil electron is ejected. But according to any form of spreading wave theory, including that of Bohr, Kramers and Slater, the scattered rays may produce effects in any direction whatever, and there should be no correlation between the directions in which the recoil electrons proceed and the directions in which the secondary β-rays are ejected by the scattered X-rays.

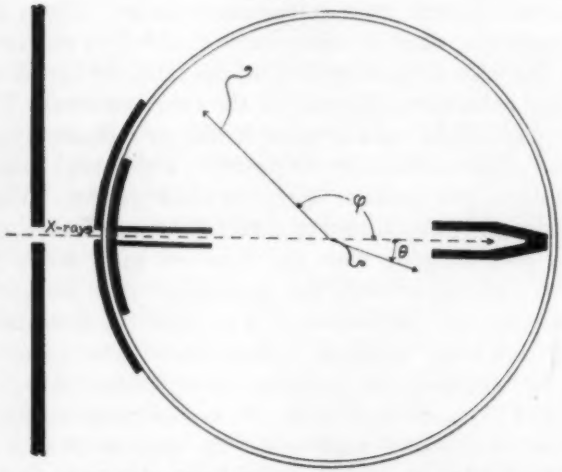
A test to see whether such a relation exists has been made,[41] using Wilson's cloud apparatus, in the manner shown diagrammatically in Fig. 3. Each recoil electron produces a visible track, and occasionally a secondary track is produced by the scattered X-ray. When but one recoil electron appears on the same plate with the track due to the scattered rays, it is possible to tell at once whether the angles satisfy equation (4). If two or three

[40] W. Bothe and H. Geiger, *Zeits. f. Phys.*, **26**, 44 (1924); **32**, 639 (1925).
[41] A. H. Compton and A. W. Simon, *Phys. Rev.*, **26**, 289 (1925).

recoil tracks appear, the measurements on each track can be approximately weighted.

Out of 850 plates taken in the final series of readings, thirty-eight show both recoil tracks and secondary β-ray tracks. On eighteen of these plates the observed angle φ is within 20 degrees of the angle calculated from the measured value of θ, while the other twenty tracks are distributed at random angles. This ratio 18: 20 is about that to be expected for the ratio of the rays

FIG. 3.



If the X-rays excite a recoil electron at an angle θ, the photon theory predicts a secondary β-particle at an angle φ.

scattered by the part of the air from which the recoil tracks could be measured to the stray rays from various sources. There is only about 1 chance in 250 that so many secondary β-rays should have appeared at the theoretical angle.

If this experiment is reliable, it means that there is scattered X-ray energy associated with each recoil electron sufficient to produce a β-ray, and proceeding in a direction determined at the moment of ejection of the recoil electron. In other words, the scattered X-rays proceed in directed quanta of radiant energy.

This result, like that of Bothe and Geiger, is irreconcilable with Bohr, Kramers and Slater's hypothesis of the statistical production of recoil and photo-electrons. On the other hand, both of these experiments are in complete accord with the predictions of the photon theory.

RELIABILITY OF EXPERIMENTAL EVIDENCE.

While all of the experiments that we have considered are difficult to reconcile with the classical theory that radiation consists of electromagnetic waves, only those dealing with the individual scattering process afford crucial tests between the photon theory and the statistical theory of virtual radiation. It becomes of especial importance, therefore, to consider the errors to which these experiments are subject.

When two point counters are set side by side, it is very easy to obtain coincidences from extraneous sources. Thus, for example, the apparatus must be electrically shielded so perfectly that a spark on the high-tension outfit that operates the X-ray tube may not produce coincident impulses in the two counters. Then there are high-speed alpha- and beta-rays, due to radium emanation in the air and other radio-active impurities, which may pass through both chambers and produce spurious coincidences. The method which Bothe and Geiger used to detect the coincidences, of recording on a photographic film the time of each pulse, makes it possible to estimate reliably the probability that the coincidences are due to chance. Moreover, it is possible by auxiliary tests to determine whether spurious coincidences are occurring—for example, by operating the outfit as usual, except that the X-rays are absorbed by a sheet of lead. It is especially worthy of note that in the fluorescence experiment the photon theory predicted absence of coincidences, while in the scattering experiment it predicted their presence. It is thus difficult to see how both of these counter experiments can have been seriously affected by systematic errors.

In the cloud expansion experiment the effect of stray radiation is to hide the effect sought for, rather than to introduce a spurious effect. It is possible that due to radio-active contamination and to stray scattered X-rays beta particles may appear in different parts of the chamber, but it will be only a matter of chance if these beta particles appear in the position predicted from the direction of the ejection of the recoil electrons. It was in fact only by taking great care to reduce such stray radiations to a minimum that the directional relations were clearly observed in the photographs. It would seem that the only form of consistent error that could vitiate the result of this experiment would be the psychological one of misjudging the angles at which the beta

particles appear. It hardly seems possible, however, that errors in the measurement of these angles could be large enough to account for the strong apparent tendency for the angles to fit with the theoretical formula.

It is perhaps worth mentioning further that the initial publications of the two experiments on the individual scattering process were made simultaneously, which means that both sets of experimenters had independently reached a conclusion opposed to the statistical theory of the production of the beta rays.

SUMMARY.

The classical theory that radiation consists of electromagnetic waves propagated in all directions through space affords no adequate picture of the manner in which radiation is emitted or absorbed. It is inconsistent with the experiments on the photo-electric effect, and is entirely helpless to account for the change of wave-length of scattered radiation or the production of recoil electrons.

The theory of virtual oscillators and virtual radiation which are associated statistically with sudden jumps of atomic energy and the emission of photo-electrons and recoil electrons, does not seem to be inconsistent with any of these phenomena as viewed on a macroscopic scale. This theory, however, seems powerless to predict the characteristics of the photo-electrons and the recoil electrons. It is also contrary to Bothe's and Bothe and Geiger's coincidence experiments and to the ray track experiments relating the directions of ejection of a recoil electron and of emission of the associated scattered X-ray.

According to the photon theory, the production and absorption of radiation is very simply connected with the modern idea of stationary states. It supplies a straightforward explanation of the major characteristics of the photo-electric effect, and it accounts in the simplest possible manner for the change of wave-length accompanying scattering and the existence of recoil electrons. Moreover, it predicts accurately the results of the experiments with individual radiation quanta, where the statistical theory fails.

Unless the three experiments on the individual events are subject to improbably large experimental errors, the conclusion is, I believe, unescapable that radiation consists of directed quanta of

energy, *i.e.*, of photons, and that energy and momentum are conserved when these photons interact with electrons or atoms.

Let me say again that this result does not mean that there is no truth in the concept of waves of radiation. The conclusion is rather that energy is not transmitted by such waves. The power of the wave concept in problems of interference, refraction, etc., is too well known to require emphasis. Whether the waves serve to guide the photons, or whether there is some other relation between photons and waves is another and a difficult question.

TALKING AND SYNCHRONIZED MOTION PICTURES.*

BY

WILLIAM H. BRISTOL, M.E.

President, The Bristol Company; Member of the Institute.

AFTER devoting over twenty-five years to the development and manufacturing of a line of recording instruments covering almost every industrial application, in which, for example, it is desired, in a manufacturing or power plant or the like, to have permanent records of pressures, temperatures, voltages, speeds, or any other physical quantities varying with time, that occur in the operation of such plants, there seemed to be very few needs or applications that had not already been taken care of by some special type of these recording instruments.

In 1915, I conceived the idea of recording simultaneously what is seen and heard in permanent form, so that such records may be reproduced at any future time or place as if the characters were really present, talking and acting.

The method chosen to accomplish this was to record simultaneously the sound on a phonograph disc at the same time that the motion pictures of the persons and scenes of action were photographically recorded on a "movie" film.

By reproducing the sound record and the film simultaneously and synchronously the sounds and actions are heard and reënacted as in the original. This method combines the two arts of phonograph recording and motion picture photography without involving any radically different methods of recording the sound or necessitating any change in the picture film itself. At the present time there are two general types of synchronized motion pictures in use—one, similar to that of the author, using a phonograph disc for recording the sound, and the other photographically recording the sound on the edge of the film.

The second method may be discussed and dismissed in a word.

It seems to the author that the advantages of the first of these two methods over the second may be summarized as follows:

If a film is broken and a piece of it is lost, there will be a

* Presented at the Stated Meeting held Wednesday, December 21, 1927.

resulting loss of both the sound record and the photographic record.

The sound record which is made on the side of the film necessarily uses up a portion of the sensitive area of the film. In the 16-mm. width of film, or other narrow films, this use limits by so much the amount of the film available for photographing the action.

In the next place, the apparatus required, both for the making of the original record and for the reproduction on the screen of the picture, is intricate and exceedingly sensitive, requiring most careful attention. Whether the sound-wave be recorded by the use of an oscillograph or the photo-electric cell, the same requirements have to be met. Wherever the picture is to be reproduced, there must be the necessary apparatus and skilled attention.

Finally, in the speaker's opinion, it will be found that the scratching and scarring of a record, due to repeated use, will mar the photographic record of the sound and will affect harmfully the reproduction of the sound.

At the beginning of my work on this development in 1915, it was realized that it would be necessary, first, that the pictures and records should be made simultaneously and synchronously. Second, that it would not be practicable to connect the mechanism for recording the sound directly to the camera in the studio.

The first thought was that possibly two synchronous motors could be used, one for driving the camera and the other for synchronously driving the sound-recording mechanism. As no synchronous motors were available which would start from rest with torque and synchronously accelerate to full speed, it was necessary to develop a synchronizing system to meet these requirements. The special synchronizing system to be described was developed, which permits making the sound records at any location simultaneously and synchronously with the taking of the motion pictures in the studio, or elsewhere.

The purpose of this paper is to present in condensed form the author's method of making and reproducing synchronized motion pictures. Particular emphasis will be given to the electrical synchronization of the original sound record with the original motion picture film and to a detailed description of simple electrical synchronizers for synchronously operating the reproducing phonograph record turn-table and the motion picture

projector, and also to a description of the method by which the motion picture film may be retarded, or advanced, with respect to the record during the very course of the projection of the film on the screen.

The design and development of the apparatus necessary for making and reproducing talking motion pictures of this type covered several fields of engineering science. Phonograph recording has always been a more or less secret process carried on behind locked doors. The knowledge and experience for doing finished work were confined to the larger phonograph companies. It was soon realized that acoustic recording for talking pictures, with a horn, would be impracticable because the person to be recorded would have to be very close to the horn in order to register, and the horn could not be concealed in the picture.

The development of the present electrical recording system, consisting of a high-quality microphone and amplifier apparatus, became available when the vacuum tube had been perfected to its present reliable and efficient form. However, since microphone and amplifier technique have been so highly developed for radio broadcasting, public address systems, sound intensity measurements and the like, it is not deemed within the scope of a general paper like this to enter into details of this part of the apparatus. It will suffice to say that the use of the microphone and amplifier allows for more latitude than the older system of horn recording, as well as affords a method of reproduction of a superior and more natural quality of the sound, which is largely due to the fact that the microphone may be highly damped in order to give a uniform frequency response; its relatively minute output may then be highly amplified and applied to a greatly damped recording device driven by the amplified energy.

Motion picture technique is well known and requires no attention here. The problem of synchronizing the sound record and the photographic image is the vital one. As already stated, it would be impracticable to attempt rigidly to fasten the recording machine with its delicate devices directly to the camera. The synchronizing system which has been developed for driving the camera and the recording machine, and also for reproducing the sound record with the motion picture, consists of two special synchronizers, one of which generates the electrical energy in its magnetic field to feed the field of the other. The rotors or

armatures of both synchronizers are energized from an alternating-current line. When the armature of one of the synchronizers is turned by an outside source of power, the armature of the other synchronizer turns the same amount and at the same speed. Torque is developed from rest with these synchronizers, thus making it possible to transmit power electrically from one synchronizer to the other, and with perfect synchronism. The principle of construction, details and applications of these synchronizers will be explained later, illustrated by slides, models, and working apparatus.

Having recorded synchronously the sound on a phonograph record and the action on a motion picture film, the next problem

FIG. 1.

to be solved was the reproduction of the picture on the screen in perfect synchronism with the sound of the record. In other words, the turn-table which rotates the sound record must be run absolutely synchronously with the motion picture projector. When this work was first begun, the ordinary phonograph was used for reproduction and was located in front of the screen, one of the synchronizers previously described being attached to the phonograph and the other to the projector.

We realized quickly that the reproduction of the sound must be electrical in character, with a loud-speaking telephone near the screen, and with the turn-table located in the booth, by the projector, for the convenience of the operator. A carbon granule phonograph reproducer was made, using a battery for energizing the carbon granules, which developed considerably more volume than the phonograph of the earlier date. This device has passed through gradual development and now affords a very simple electrical reproducer without vacuum tube amplification. An illustration of this carbon pick-up is shown in Fig. 1.

Inherent limitations in the carbon granule device have resulted in a further development of a high-quality electromagnetic pick-up

which will be later described in detail. An amplifier and loud speaker have been developed to complete the sound-reproducing system.

In the exhibition of the talking motion pictures the film is started at a marked point at the beginning of the film, and the reproducing needle is engaged in the beginning of the first groove, this groove being eccentric and easy to locate.

When the complete apparatus is set into operation, the picture and sound will be in perfect synchronism and will stay so throughout the length of the film record.

In actual service, films are often injured and sections cut off. In making repairs care should be taken to replace pieces of film of the same lengths as the parts that have been cut out, so that perfect synchronism will be maintained. In order to provide against errors that might be made in making repairs of the film, or, possibly, to provide against an error in locating the starting-point of the film in the projector, or in setting the needle on the starting-point of the record, a unique re-synchronizing method has been devised. By means of this method the film may be advanced or retarded with respect to the sound record, even during the projection of the pictures, without affecting the quality of the sound reproduction.

Thus, we have a perfect synchronizing system which affords opportunity of making corrections for any possibility of imperfect lengths of film or permits the operator to make corrections for accidental errors in starting—all without stopping the performance.

This unique feature is accomplished by mounting the field winding frame of one of the synchronizers in trunnion bearings within which the armature bearings are located, thus allowing the field frame of one of the synchronizers to be rotated with reference to its armature independently of the rotation of the armature.

When one of the armatures is revolved at a given speed, its speed with reference to its field can be changed by rotating manually the field frame in its trunnion bearings. Ordinarily, when transmitting power from one of the synchronizers to the other the field frames are stationary, and the speed of the second armature will be the same as that of the first. If the field frame of the first synchronizer is rotated, the speed of the second armature

will be the same as the new speed of the first armature relative to its field, and not the *actual* speed of the first armature. This will be further described and illustrated with models.

As has already been pointed out, success in originally producing synchronized phonograph records and motion pictures depends upon the use of electrical synchronization so that the phonograph record of the sound may be made at any desired distance away from the motion picture camera. However, in the reproduction of the phonograph records synchronously with the projection of the pictures on the screen, systems of direct mechanical connection between the phonograph turn-table and the projector are being used to-day. These directly mechanically connected turn-tables and projectors do not afford any opportunity for re-synchronization without introducing differential gearing, or some mechanical equivalent which would be more or less complicated and tend to introduce vibrations which would seriously affect the perfect reproduction of the sounds, especially of music.

As has already been indicated, it will be seen that the electrical synchronizers which have been previously described afford ideally simple means for re-synchronizing. A striking feature of the working of the two synchronizers is that their action is not affected by considerable variation of the voltage, or of the frequency, of the alternating current by which the rotors are energized. Other advantages of this electrical system of synchronizing will be presented later.

We will now describe the basic principles upon which the synchronizers are constructed and also the method of re-synchronizing. For a period of years, I had used similar systems for recording and indicating motion at a distance; the solution of the synchronizing problem was a natural outgrowth of this work.

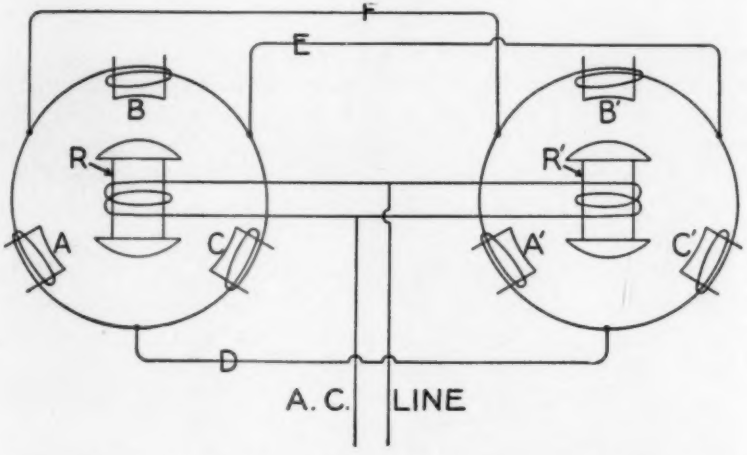
When in 1915 application was made for a patent on the synchronizers for synchronizing phonograph records and motion pictures, it was discovered that the fundamental principle involved had been patented previously by Dr. Carl J. A. Michalke, of Berlin, for the purpose of indicating and transmitting motion to a distant point.

Fig. 2 is a diagrammatic representation of two synchronizers. The rotors, or armatures, R and R', are fed from the alternating-current line as indicated, while the field windings A, B,

C and A', B', C' are interconnected, as shown, by wires D, E and F.

Assume that the power is to be transmitted from the rotor, or armature, R to R'. When the alternating current is turned on, both rotors will instantly take corresponding positions with reference to the field windings A, B, C and A', B', C'. In the position of the rotors as shown in Fig. 2, the rotor R is inducing voltage in its field windings A, B and C. The voltage in B being at its maximum, since the lines of magnetic flux are parallel to the axis of the core at the rotor. In A and C the induced voltages

FIG. 2.



are equal but each less than in B. These voltages are transmitted through the wires D, E and F to their corresponding windings A', B', C', thus producing three magnetic forces acting on the armature R', which will hold it in an equilibrium position as if the rotors were electrically geared together.

If a source of power is applied to rotor R, revolving it through an angle in a clockwise direction, the voltage induced in the field coil B will decrease to a point of no voltage after the rotor R has turned through an angle of 90°, bringing the magnetic lines of the rotor R perpendicular to those of the field coil B. In the meantime the voltage of the field coil C has decreased to no voltage and has begun to increase toward the maximum. In the coil A the induced voltage has passed through the maxi-

mum point and has begun to decrease. From this it will be seen that as the rotor R is revolved, maximum voltages are induced in its field coils one after the other in a counter-clockwise rotation exactly corresponding in rate to the rotation of the rotor R in a clockwise direction.

It will be readily understood that the varying voltages induced in the field coils A, B and C will be transmitted through the wires D, E, F to the corresponding field coils A', B', C', where they will cause corresponding magnetic forces on the rotor, or armature, R', which will make it revolve exactly as rotor R is revolved and with power corresponding to the electrical energy induced in the field coils.

The amount of power which it is possible to transmit with synchronizers of this kind is not limited, but depends upon the size, mechanical construction and electrical energy supplied to the rotors. In the present application, the synchronizers are made to transmit as much as one-quarter horsepower and are about the same size as a modern quarter horsepower electric motor.

Fig. 2 may also be used to explain the fundamental principles of re-synchronization.

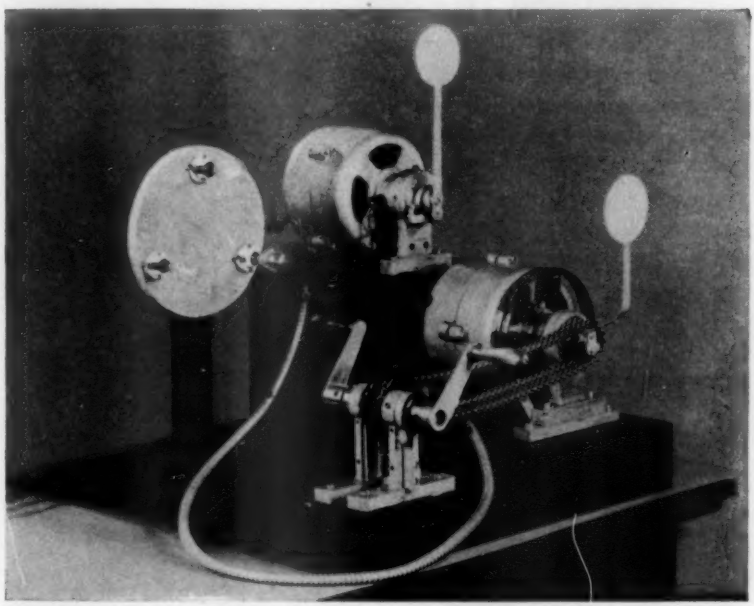
Suppose the field A, B, C is rotated one revolution in the same direction as its armature R, while the armature itself has turned through ten revolutions, the armature R will actually have turned only nine revolutions *with reference to the field A, B, C*. The rotor R' will therefore only have turned nine revolutions, although R has *actually* revolved ten revolutions.

Again, suppose the field A, B, C is turned one revolution in a direction opposite to that of its armature R, while the armature itself has turned through ten revolutions. The result will be that the armature R has made eleven revolutions *with respect to its field A, B, C* and the armature R' will then have made eleven turns, although the armature R has actually made only ten revolutions.

The working model shown in Fig. 3 has been made to illustrate, by actual operation, the foregoing principles of the synchronizer and the method of re-synchronization. Two synchronizers are connected by a small cable containing five wires, two of which furnish the alternating-current supply to the rotors. The other three are the interconnecting wires between the fields. These three wires divide the field windings each into three equal parts,

and on the finished synchronizers, the windings are distributed similarly to those of an induction motor. The rotor of the synchronizer shown in the front of Fig. 3 can be revolved in either direction by the chain drive by means of the front handle, while the field of this synchronizer may be rotated in either direction by the rear handle. Each armature is provided with a pointer so shaped that the armature motion may be easily followed.

FIG. 3.

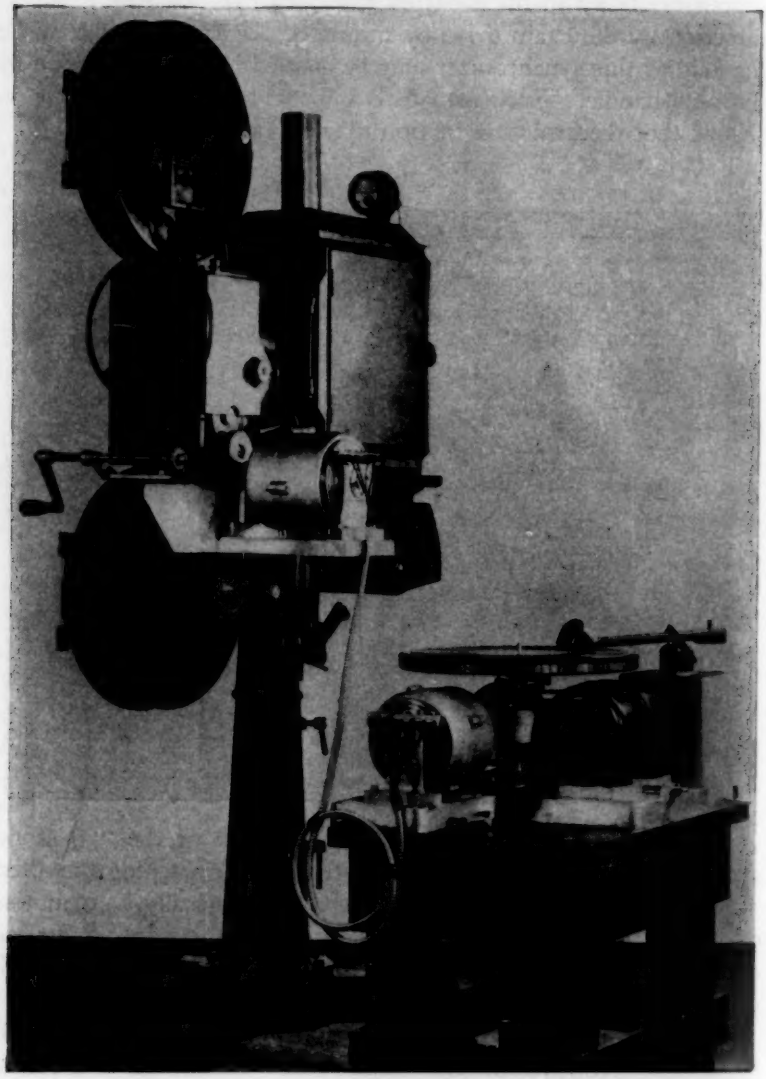


We are now ready to show the operation of the two model synchronizers. It will be observed that upon switching the alternating current to the armatures there will generally be a motion of one or both of the armatures, bringing them into magnetic equilibrium or what might be called throwing them into electric gear, as previously mentioned.

If the armature of the front synchronizer is now revolved in either direction, the armature of the rear synchronizer will follow in step at all different speeds.

On the disc at the left of Fig. 3 are mounted three small incandescent lamps connected across at the three equidistant points

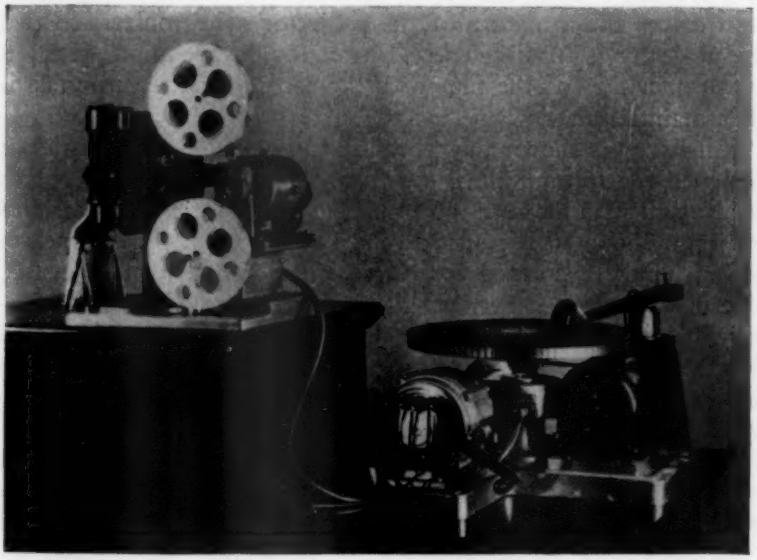
FIG. 4.



of the fields. When the armature of the front synchronizer is turned, these lamps show by their increasing and decreasing brilliancy the varying induced voltages generated in the three field sections. As previously explained, these lamps show how the maximum induced voltages occur around the field in a direction opposite to the direction of the motion of the armature.

To illustrate the method of re-synchronization by the model, if the armature of the front synchronizer is rotating at a constant

FIG. 5.



speed, the pointers will show that both armatures are turning exactly together. Then to retard the armature of the rear synchronizer, the field of the front synchronizer is revolved by the rear handle in the same direction that the armature is moving. The amount of retardation will be governed by the number of turns or fraction of turns of this field, and the pointers will continue to revolve at the same speed but angularly separated.

Again, assuming that the armatures of both synchronizers are revolving together, in order to advance the armature of the rear synchronizer, the field of the front synchronizer is turned in a direction opposite to that of the rotation of its armature.

In Fig. 4 a motion picture projector for standard width film is shown with the synchronizer attached for driving it with its re-synchronizing handle at the left, convenient for the operator. At the right of Fig. 4 is shown the turn-table on which the record is placed. Beneath the turn-table on the left side, its synchronizer is shown; attached to it is a five-wire cable which is the only connection between the turn-table synchronizer and the projector synchronizer. The motor located beneath the turn-table on the right side drives the turn-table through the worm and gear and also drives the armature of the turn-table synchronizer, which in turn drives the armature of the projector synchronizer, so that the projector is furnished with power for its operation. Perfect synchronization of the film with the record on the turn-table is thus maintained.

In Fig. 5 is shown a synchronizer applied to a small projector designed for 16-mm. films, together with a turn-table unit which is identical with the turn-table unit employed for the professional projector shown in Fig. 4, with the exception that the re-synchronizing handle is located for convenience on the turn-table unit. The only connection between the synchronizers is the usual five-wire cable shown in Fig. 5. This particular outfit has been designed to bring talking moving pictures into the school and the home. It will be understood that these synchronizers can be applied to any model of motion picture projector.

Fig. 6 shows the universal turn-table unit suitable for use with all types of projectors. In this illustration is shown the governor, which maintains absolutely constant speed, this being of vital importance for the reproduction of music.

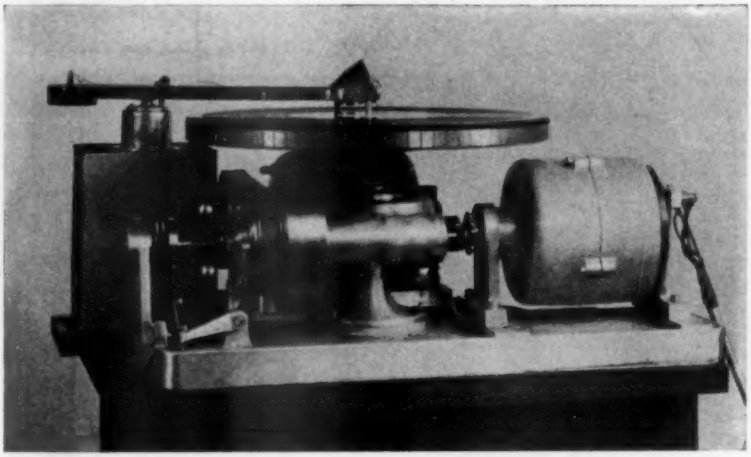
From the descriptions and illustrations already shown, it may be seen that the turn-table unit consists simply of a driving motor, a governor, a worm and gear and one of the synchronizers. The other synchronizer is attached to the projecting machine on a suitable bracket, the two synchronizers being connected only by the five-wire cable. There are no commutators to wear or spark, and there are no make or break contacts to cause trouble. Ball-bearings are used throughout, thus requiring the minimum of oiling and attention.

The electrical synchronizing system has several advantages as compared with direct mechanical connection between the turn-table and the projector. First, the simplicity of the installation;

a synchronizer can be easily secured to the projector by a suitable bracket and connected by the five-wire cable to the turn-table synchronizer, which is a part of a self-contained unit that may be located at the most convenient place. No further adjustments need be made on this turn-table unit at the time of installation. Second, the ability to re-synchronize. Third, the advantage of being able to apply the synchronizing system to any projector, whether made for standard width or 16-mm. width film.

The sound-reproducing system consists of three parts, the electrical pick-up, an amplifier and a loud speaker. The faith-

FIG. 6.



fulness of reproduction depends on the quality of each part of the system and is no better than any one of the parts.

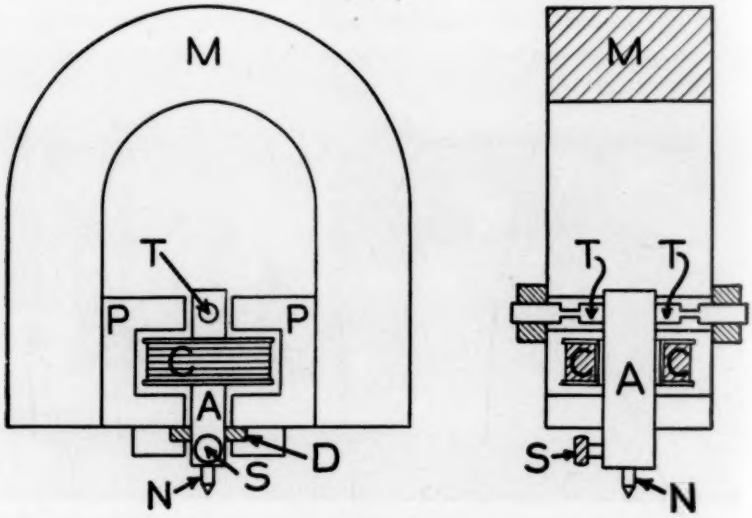
The function of the electrical pick-up is to convert the mechanical undulations of the phonograph record groove into corresponding electrical oscillations. Any of the well-known principles used for microphone, or loud-speaking devices, might be adapted for this purpose, but the electromagnetic principle was selected because of its adaptability to light vibrating parts, its simplicity and ruggedness, and because, with proper design, a high degree of fidelity of reproduction was possible.

The magnetic pick-up consists of a light soft iron armature torsionally held between magnetic pole pieces, and surrounded by a coil. Motion, as imparted by the needle in the phonograph

record groove to the armature, causes an oscillating magnetic flux along the armature corresponding to the needle movements; these magnetic variations produce corresponding voltages across the terminals of the coil surrounding the armature.

The mechanical and electrical structure of our pick-up is shown in Fig. 7. The armature *A* is supported by the torsion suspension *T*, so as to be held equidistant from the pole pieces, *P*, *P*. The needle is secured to the armature by the set screw *S* and movements of the needle displace the armature around the

FIG. 7.



torsional axis *T*, increasing and decreasing the gaps between it and the lower pole pieces, thus changing the magnetic flux in the armature.

There is practically no motion of the armature in the upper gaps, the lower gaps being the active ones.

The rubber pads, *D*, furnish damping for the armature. A main feature of the construction of this pick-up is its ruggedness and reliability as the armature is maintained exactly centrally between the pole pieces by the torsion suspension *T*.

A special amplifier has been designed for use with this electromagnetic pick-up; also, a long horn, as shown in Fig. 8, has been developed for reproduction of speech and music in large auditoriums.

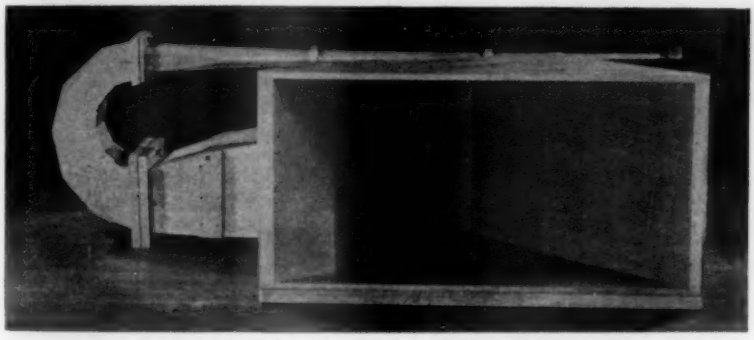
In the taking of motion pictures, it is of prime importance that there be no sounds other than those to be recorded. Therefore, when a picture is taken, the camera is placed in a sound-proof booth, as shown in Fig. 9, in its position for taking a picture of a typical scene.

In Fig. 10 is shown an exterior view of the sound-proof booth and a portion of the scene that was used in a talking motion picture.

A view of the recording machine with a wax disc for making the original record is shown in Fig. 11.

The applications for these synchronized pictures are not limited to theatres but may be used for industrial, and particularly for educational, purposes. In the theatrical field, synchronized and talking moving pictures are being successfully used as produced by the Vitaphone system, with a phonograph turn-table directly connected to the projector, and by the DeForrest and the Case-Fox systems, where the sound is photographed on the edge of the film. It has been demonstrated that the public approves of both these types of synchronized motion pictures for vaudeville sketches, news reels and the like, and also for mechanically reproduced orchestral music, synchronized with pictures which have previously been made. Complete talking motion picture dramas have not as yet been presented to the public, but there is no reason why they may not be produced with the present, or any other, synchronized apparatus.

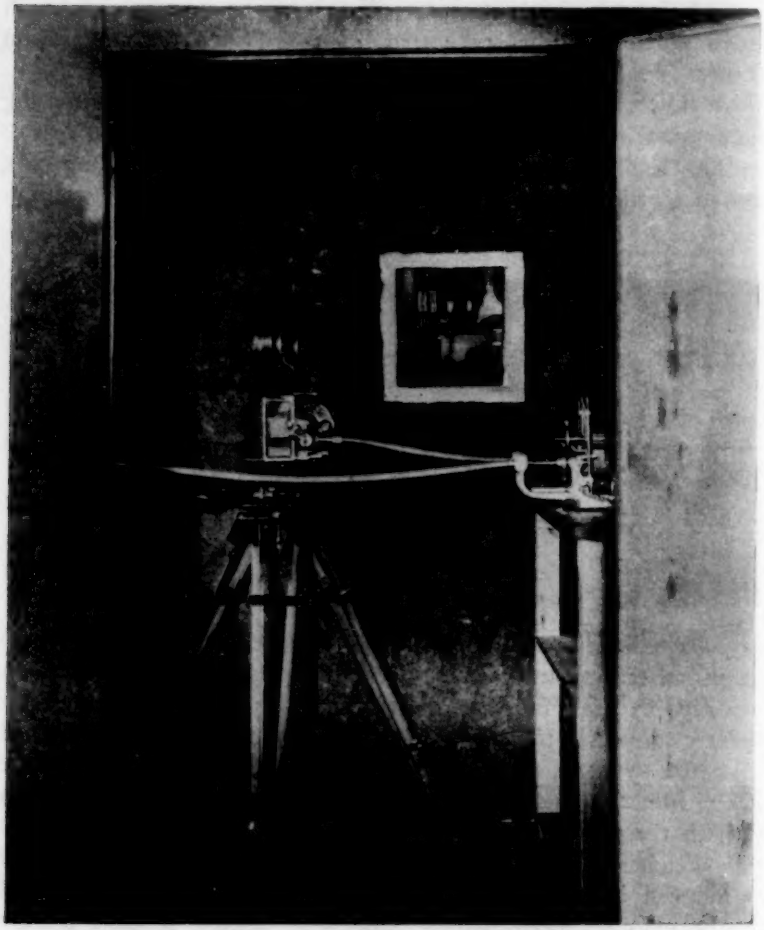
FIG. 8.



Most of the so-called "educational films" that have been, or are being, distributed should be included in the industrial class, as

they are usually primarily for indirect advertising; there exists a large field for this class of motion pictures when synchronized with the voice to tell the story which will make the pictures more

FIG. 9.



interesting and entertaining. For truly educational purposes, motion pictures are already firmly established in the field of visual education, but by the addition of synchronized sound, their value will be greatly enhanced, as it will make it possible for the greatest

FIG. 10.

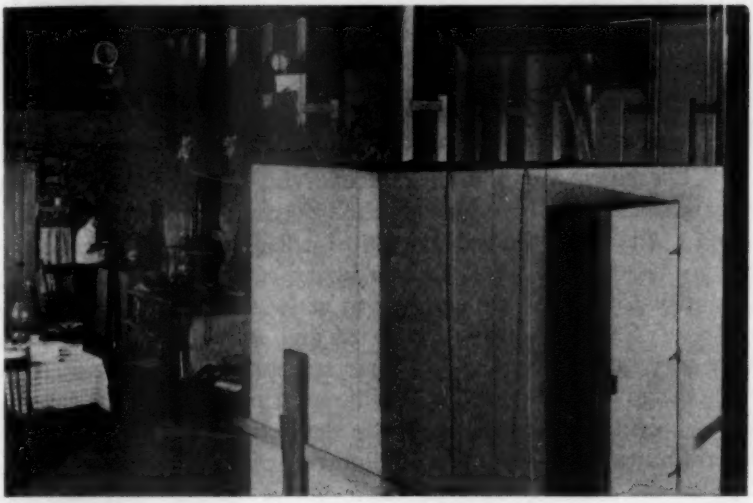
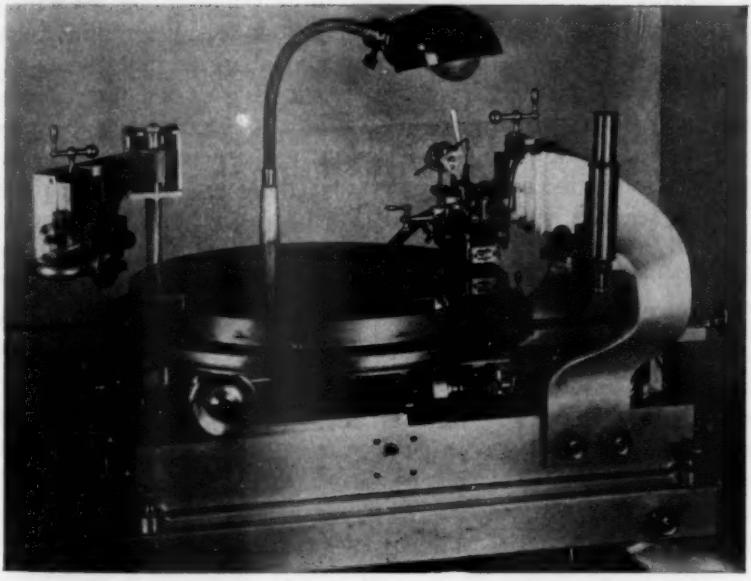


FIG. 11.



teachers, lecturers and authorities to be seen and heard at any time and in any place.

I will now let a good friend tell you from the screen what he thinks of the possibilities of talking moving pictures.

A TALK BY JOE MITCHELL CHAPPLE ON THE POSSIBILITIES OF THE SYNCHRONIZATION OF MOTION PICTURES AND SOUND.

"The object of thousands of experiments and of exhaustive research has resulted in one of the greatest triumphs of modern times. The range of possibilities of what you are looking upon now is beyond the most extraordinary imagination. Think of President Coolidge here before you with every word of his voice and every motion of his lips heard and seen distinctly as if he were here in the flesh. All this can be reproduced simultaneously to thousands of audiences and millions of people in every country in the world. This is its ultimate development—enjoyment and entertainment are no longer the luxuries of the few but the heritage of the masses. It is to make our work play and our play work. We have entered a Golden Age where the wealth of knowledge of those things contributing to human happiness may be distributed in homes, in schools, in all public places, as widely as the wind that blows and the air we breathe. Every individual having eyes to see and ears to hear may share in the all-comprehensive privileges that have come with this marvellous achievement. It has even transcended the ideal of democracy dreamed by Jefferson, achieved by Washington and perpetuated by Lincoln, giving specifically to each individual the equal, the inalienable right to see and hear the best that is to be seen and heard in his day and generation. What would we give if we could look upon this picture and see the immortal Lincoln in the flesh and hear that voice as he spoke those words at Gettysburg? Truly the wonders will never cease."

THE SENSITOMETRY OF THE BICHROMATED GELATIN PROCESS.

BY

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INTRODUCTION.

A FEW years ago, Mees [1] described a method of using the bichromated gelatin process to make colored photomicrographs of subjects, such as biological specimens, which are stained in either one or two colors. The success of this method when used in our laboratory suggested an attempt to adapt it to the photography of subjects presenting a greater variety of colors. To do this, a knowledge of the sensitometry of the bichromated gelatin was prerequisite.

The sensitometry of gelatino-bromide materials has been studied extensively and a standard procedure (summarized by Jones in this JOURNAL [2]) has been developed for it. Apparently, however, very little has been done on the bichromated gelatin process, although it was described as early as 1885. A search through the literature disclosed very few papers,* and these did not contain the kind of data we needed.

We were therefore obliged to undertake this investigation, and are presenting the results for the benefit of others who may wish to use this method for the preparation of transparencies in any number of colors. It is hoped that they will be of value to those pictorial or scientific photographers who desire to make colored transparencies, and also that they may offer some suggestions to photo-engravers and others who are using closely allied processes.

The essential features of the method of preparing two-color transparencies will be presented by stating briefly the directions given by Mees. Two negatives are first made on panchromatic plates, each being exposed behind a filter which is complementary to one of the two colors in which the subject was stained. Two lantern slide plates are then prepared by being sensitized in a solution of ammonium bichromate, rinsed briefly, and dried in

* See especially Richter [3] and Eder.[4]

a gentle current of air. These are then exposed *through the glass* behind the negatives to a small source of light, one of the negatives being reversed so that its emulsion side faces the light. The action of the light is to make the gelatin of the bichromated plates insoluble in hot water. They are then *etched* in hot water until the soluble gelatin is removed and a gelatin image in relief remains. These *matrices* are then "fixed" in hypo, rinsed, washed and dried. Each matrix is then dyed to a color simulating one of the two colors of the subject and, finally, the two are bound with their gelatin sides together to make a lantern slide.

Although the type of subject that Mees assumed was a very simple one, the substitution of complementary red and green taking filters and the proper red and green dyes will yield reasonably good results for subjects which do not contain blues or saturated yellows provided the requirements of correct tone reproduction are satisfied. This implies a knowledge of the sensitometric characteristics of the material, and the method of determining these will first be presented.

I. DESCRIPTION OF PROCEDURE.

The sensitometric method of studying the behavior of photographic plates was first used on the ordinary gelatino-bromide plates by Hurter and Driffield in 1890, and their method of investigation is too well known to require more than passing mention. In brief, the procedure as followed to-day is to expose the sensitive material in some characteristic manner, usually by giving a graded series of exposures in which each exposure is double the preceding one. This constitutes a sort of standard subject which is easily controlled and is exactly reproducible. The sensitive material is then developed and the amount of light absorbed by each step of the developed image is measured. From these data, a curve can be plotted showing the relation between the amount of blackening (optical density) and the exposure which produced it. When the exposure is plotted on a logarithmic scale, this curve is known as the *characteristic curve* of the material and all of the important characteristics of the material can be read directly from it.

In the present investigation we followed a similar procedure with the modifications demanded by the insensitivity of our material. In our preliminary work we had followed exactly the

technique recommended by Mees [1] for processing the plates. From the characteristic curves thus obtained, we had found that this technique might be improved in some minor details, so we adopted this improved technique as a standard. Then we investigated each step of the process individually by varying the conditions under which it was performed while adhering to the standard technique elsewhere. At the close of the investigation we found that our technique, which we adopted because it was the most satisfactory one we knew at the time, apparently could not be improved for making pictures. It is described in detail below. The variations from it made at each stage of the investigation are described in their appropriate places in Part III since they were made only temporarily.

(1) *Sensitizing.*—The sensitizer recommended by Mees was used without modification. The formula is as follows:

Ammonium bichromate	25 gm.
Water	1000 c.c.
Ammonia (sp. g. 0.88)	5 c.c.

This solution may be used repeatedly but should be filtered each time. The standard time and temperature for sensitizing were five minutes and 55° to 65° F.

Throughout the investigation, Eastman Slow Lantern Slide plates of the same emulsion number were employed. It was generally found convenient to sensitize them two at a time in a tray. When more plates were required, they were sensitized in a $5'' \times 7''$ plate tank with a capacity of one dozen plates.

(2) *Drying.*—After the plates were taken from the sensitizer, they were rinsed under the tap for a few seconds and set in racks to dry. Rinsing was made very brief so that the sensitizer would not be washed from the outer layers of gelatin, thus shortening the latitude by reducing the thickness of sensitized gelatin.

Drying was accelerated by placing the plates two or three feet from a fan because bichromated gelatin becomes insoluble rapidly when wet. Care was taken to avoid a strong draft because this has a tendency to cause streaks of uneven sensitivity.

(3) *Exposing.*—As soon as the plates were dry, they were exposed through the glass to a tipless 1000-w. Mazda C lamp furnishing 1480 candle-power in the direction of the plate. They faced the end of the lamp and were two feet from the filament,

the illumination on them being 370 foot-candles or 4000 meter-candles. The sensitometer, especially designed in this laboratory for slow materials, provided twelve power-of-two steps on a time scale, the longest time of exposure being 800 seconds. Occasionally a hand-controlled step of 1600 seconds was added.

(4) *Etching.*—As soon as the plates had been exposed they were etched in water at 130° F. for four minutes. The apparatus consisted of a monel metal cage into which the plates were loaded and which was immersed in a monel metal tank containing approximately 10 litres. The tank rested on an electric stove by which the temperature was kept constant to ± 1° F. The cage was supported by a string by which it was raised and lowered about four inches, thirty-six times a minute by a motor.

After etching, the cage containing the plates was dipped into a tank of tap water and raised and lowered several times to remove any loose gelatin.

At this stage of the process, the gelatin relief image (matrix) still contains the silver halide, some of which has been darkened slightly so as to render the different exposure steps distinctly visible. This almost entirely disappears during the fixing process which follows, leaving an image consisting simply of different thicknesses of transparent gelatin.

(5) *Removal of Silver Halide.*—The matrices were "fixed" in a 30 per cent. solution of plain photographer's hypo until the white silver halide was entirely dissolved. Frequently the plates appeared slightly cloudy when removed from this solution, especially if the latter was not perfectly fresh, but this seemed to do no harm and largely disappeared during washing.

(6) *Washing and Drying.*—The matrices were washed for from ten minutes to an hour in water flowing from a tap. They were dried either in still air or in front of a fan, whichever was more convenient, since drying conditions at this stage are probably unimportant.

(7) *Dyeing.*—The dry matrix is simply a transparent gelatin relief resembling a flight of steps. The thickness of each step might have been determined by appropriate mechanical means and used as a measure of the effect of the exposure. However, the useful property of the matrix is its ability to absorb a dye in varying quantity, and we were not certain that the absorption of light by the dyed matrix is related in any simple manner to its

thickness, since the light may also produce a differential hardening towards the action of the dye. For this reason we decided to dye the matrices and then measure their light absorption.

We selected a convenient red dye, Newport Acid Scarlet 2R, for the sole reason that it had been used in some previous work. The matrices were bathed in a 0.5 per cent. solution of this for thirty-two minutes, and on removal were placed on a slanting board where the surplus dye on the surface was blown off by compressed air.

(8) *Density Measurement.*—If T represents the ratio of the amount of light transmitted by an absorbing medium to the total amount of light incident on its surface, the optical density is defined by

$$D = \log \frac{1}{T}.$$

In gelatino-bromide sensitometry, white light is used as a source for density measurement and is transmitted by the developed image without appreciable change of quality. In our case the image was dyed red and precise readings would have been impossible with white light as a source because of the color difference in the photometric field. For this reason, a Cooper-Hewitt Lab-Arc was used as a source of light, a Wratten No. 62 filter being used to screen off all the visible radiation except the green line. It should be remembered that the density values determined in this manner are significant only in connection with this particular dye and with monochromatic light of this particular frequency.

For controlling characteristics in practical picture-making, a lower precision than that required in this investigation is permissible so that a simpler method of determining characteristics can be used. This method will be outlined later.

II. THEORY OF THE PROCESS.

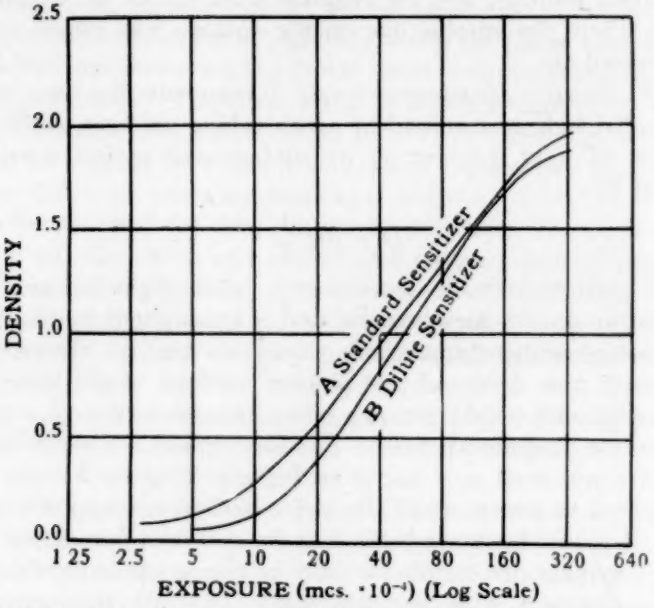
When the density of each step of a sensitometric strip, prepared as described above, is plotted against the logarithm of the exposure producing it, a curve like Curve A of Fig. 1 results. It is similar to that of a gelatino-bromide plate. The equation of the straight-line portion is

$$D = \gamma (\log E - \log i), \qquad (1)$$

where D is the density corresponding to exposure E, γ is the slope

of the line, and log i is the intercept on the log E axis. The quantity i is called *inertia* and is an inverse measure of the speed of the material. For correct reproduction of the tones of the subject, all exposures must be kept within this straight-line portion of the curve.[2] The limits of this portion—the region of

FIG. 1.



Effect of diluting the sensitizer. *A*, standard formula given in text. *B*, same formula but half as strong.

correct exposure—are the *toe* and *shoulder*, which are the regions of under-exposure and over-exposure, respectively.

The derivation of equation (1) from purely theoretical considerations is simple provided the gelatin, which actually contains small particles of silver halide, is considered to be homogeneous. Let I be the illumination of the surface of the gelatin nearest the light during exposure. If the absorption coefficient of the gelatin is a, the illumination at a distance x from the surface is

$$I_x = Ie^{-ax}, \tag{2}$$

according to the law of absorption. Consequently the exposure at a distance x from the surface is

$$E_x = I_x t = Ite^{-ax} = Ee^{-ax}, \tag{3}$$

where t is the time of exposure and E is the exposure at the surface. Therefore

$$ax = \ln E - \ln E_x = k(\log E - \log E_x), \tag{4}$$

k being the factor which converts natural logarithms to common ones.

Etching the plate removes all gelatin below a degree of hardness depending upon the etching time and temperature. The resulting matrix is bounded on one side by the glass support and on the other by a surface over which the hardness or, more precisely, the solubility, is constant. This surface of equal hardness will be called the *isosclerotic surface*. It is evidently characterized by the feature that the exposure E' over it is constant. Of course there are an infinite number of such surfaces, but we shall restrict the meaning of the term to the one bounding the matrix. Therefore the thickness of the matrix is

$$\Delta = \frac{k}{a}(\log E - \log E'). \tag{5}$$

Under the proper dyeing conditions, the dye may be assumed to be uniformly distributed so that the light absorption b of every unit cube of gelatin throughout the matrix is the same. Then if J is the amount of light incident on a unit area of the plate when the latter is viewed, the amount of light transmitted where the thickness is Δ is

$$J' = Je^{-b\Delta}. \tag{6}$$

By definition the density at that point is

$$D = \log \frac{J}{J'} = \frac{1}{k} \ln \frac{J}{J'} = b\Delta. \tag{7}$$

Combining equations (5) and (7),

$$D = \frac{b}{a}(\log E - \log E'). \tag{8}$$

This exactly corresponds with equation (1) if we put

$$\gamma = \frac{b}{a} \tag{9}$$

and

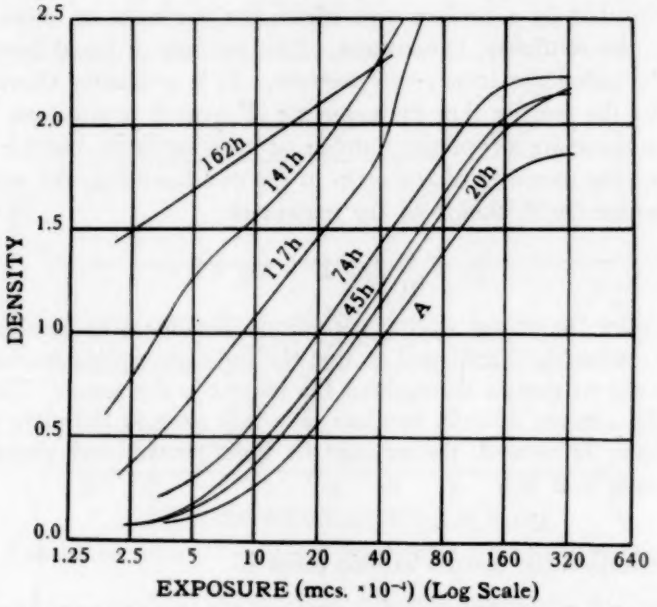
$$i = E'. \tag{10}$$

III. RESULTS OF THE INVESTIGATION.

As has been mentioned in Part I, a single operation was studied by varying the conditions under which it was conducted while a standard technique was adhered to elsewhere. The effects of variations in these conditions will now be described.

(1) *Concentration of Sensitizer.*—The only experiment performed upon the sensitizer was to dilute it to 50 per cent. of the

FIG. 2.

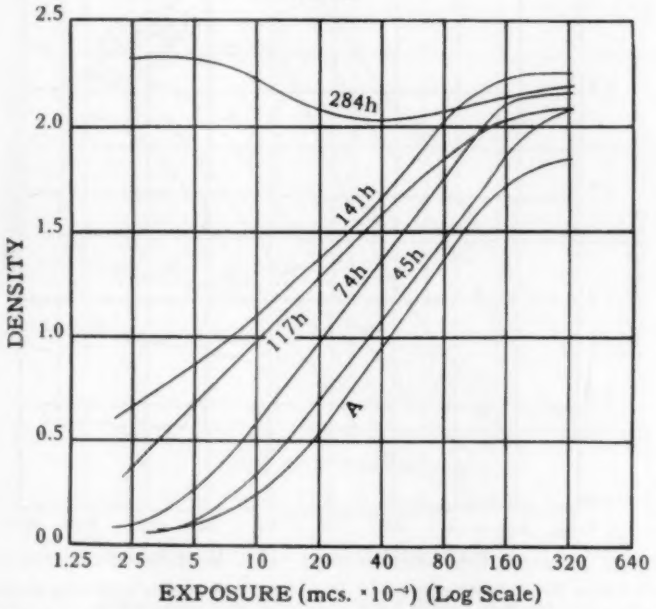


Effect of storing the plates in a rack in a dark room for the indicated number of hours after sensitization. Curve *A* is of plate exposed as soon as sensitized.

standard concentration. The result of this was an increase in gamma and inertia as shown in Fig. 1. This agrees with the results of other investigators.[4] The increase in gamma is due to the reduction of the value of a in equation (9), resulting from the weakening of the yellow bichromate stain. The increase in inertia—about 50 per cent.—is probably due to chemical causes. Its magnitude relative to the change in concentration of the sensitizer is about what was noticed by Eder. Since the plates are so slow, it might be worth while rather to try to decrease their inertia.

(2) *Sensitizing Conditions.*—The conditions under which the plates are sensitized are unimportant within wide limits. Plates were sensitized for 2½, 5, 10 and 20 minutes at 40°, 50°, 60° and 70° F. The characteristic curves of all these plates were very similar and so are not presented. When sensitized for five minutes the spread in gamma was from 1.49 to 1.60—easily within experimental error. The plates sensitized for other times

FIG. 3.



Effect of storing the plates in a box in a dark room for the indicated number of hours after sensitization. Curve *A* is of plate exposed as soon as sensitized.

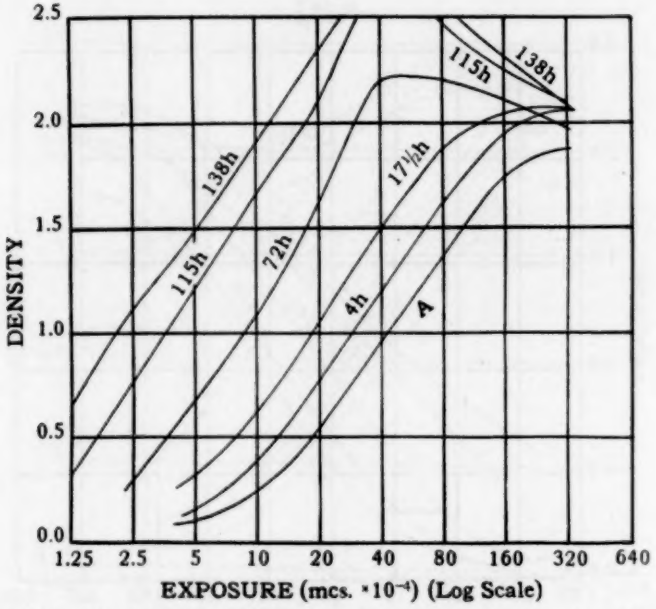
had sensibly the same gammas but slightly different inertias. The spread in inertia time was about four seconds or 15 per cent., and the variation was not systematic. As can be seen from Fig. 14, this variation is negligible compared with that produced by unknown causes.

The plates sensitized at 70° varied widely in inertia and were irregularly etched at the higher densities. A plate sensitized at 80° could not be used because the gelatin softened. For this reason a temperature below 65° F. is advisable, but a temperature below 55° seems to reduce the latitude somewhat.

The time of sensitizing did not seem to make much difference, the only requirement seeming to be that the gelatin become thoroughly soaked. Even 2½ minutes was enough.

(3) *Keeping Qualities.*—The effect of storing the plates after they have been sensitized is pronounced, as Figs. 2 and 3 show. These curves are of plates which were sensitized together and

FIG. 4.



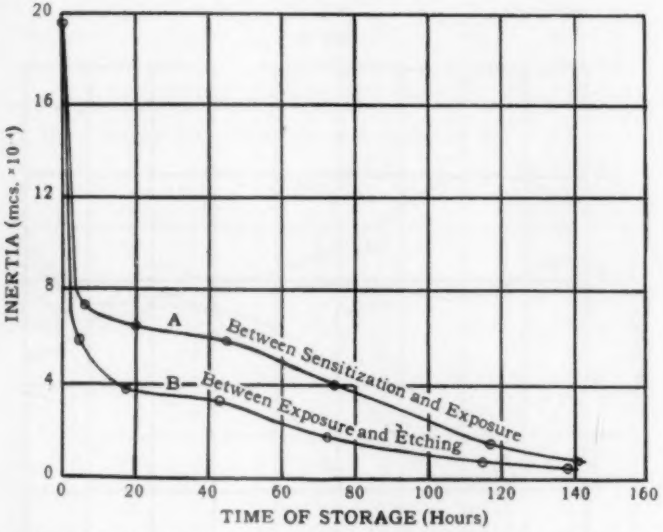
Effect of storing the plates in a rack in a dark room for the indicated number of hours after exposure. Curve *A* is of plate etched as soon as exposed.

then exposed after the lapse of the intervals of time indicated. The plates of Fig. 2 were stored in a dark room while those of Fig. 3 were stored in a box with their gelatin sides facing each other but separated by the spacers which had been used originally in packing the plates.

The important feature shown by these curves is that the inertias decrease (or speeds increase) progressively from the first; and those of Fig. 2 plotted against time of storage result in Curve *A* of Fig. 5. Apparently the most convenient time to use the plates would be when they are between 20 and 40 hours old because their speed is fairly constant during this interval.

However, the surface of the matrix at the higher densities becomes roughly etched after about ten hours, and after about seventy hours the etching is markedly irregular, large portions of the gelatin that should have dissolved remaining in place. When a plate is fresh the gelatin etches off in minute particles,

FIG. 5.



Variation of inertia with time of storage. Data for Curve *A* from Fig. 2; data for Curve *B* from Fig. 4.

but as the plate ages the size of the removed particles increases. This reduces the resolving power of the plates.

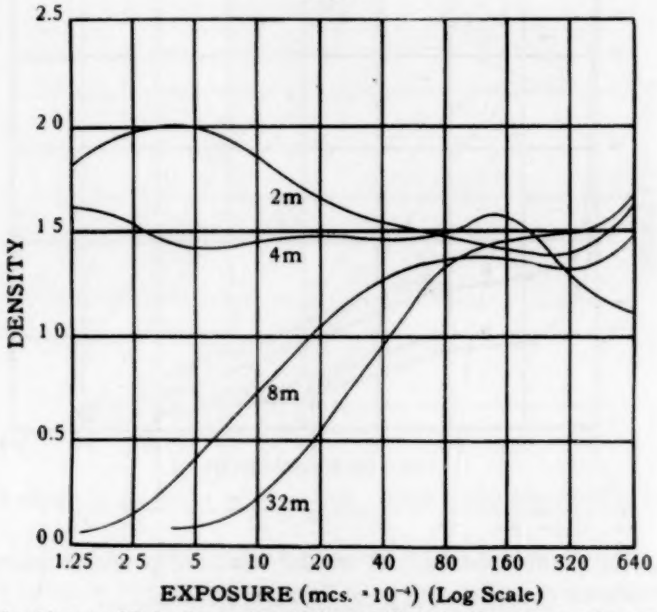
(4) *Fading of the Latent Image.*—The plates also increase in speed if stored after being exposed, but at a slightly faster rate than in the preceding case. Fig. 4 and Curve *B* of Fig. 5 demonstrate this. These curves are of plates which were sensitized together, allowed to dry, exposed immediately, and etched thereafter at the times indicated. Here again the phenomena described in the preceding section were observed except that the variation with time was greater. Evidently plates should be etched as soon as possible after exposure.

Eder [4] also obtained, qualitatively, the results described in this section and the preceding one. He noticed also that the humidity of the room in which the plates are stored affects the rate of

change of speed, a high humidity being conducive to a rapid change.

(5) *Etching Conditions.*—The effect of a high temperature or a long time of etching is to decrease the speed (increase the inertia) of the material but not to alter its gamma. Figs. 7 and 8 make this clear. Such a result might be predicted theoretically since an increase in etching time or temperature should increase

FIG. 6.



Effect of etching at 90° F. for the number of minutes indicated. Note the negative gamma of the two-minute and four-minute curves.

the inertia E' by pushing the isosclerotic surface nearer the glass. Gamma should not be affected since by equation (9) it depends upon the optical absorption of the gelatin only.

The relation between etching conditions and inertia is more clearly shown by Fig. 9, where inertia is plotted against etching time for five etching temperatures. The points for each temperature seem to lie on a curve whose equation is

$$i = i_m (1 - e^{-kt}), \qquad (11)$$

where i_m is the maximum inertia (for $t = \infty$) and k is the time rate of increase of inertia. Such a curve was drawn for each

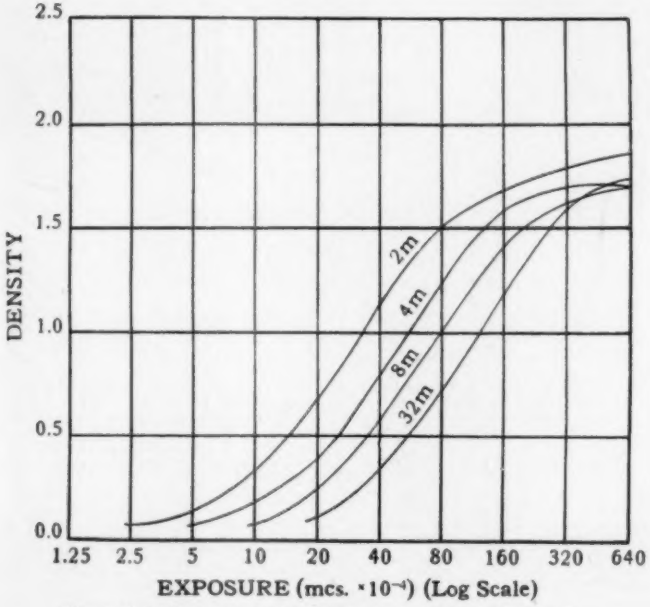
temperature, the values of k and i_m being computed from the coördinates of the four-minute and the thirty-two-minute points. These values are given in Table I.

TABLE I.

θ	k	i_m
140°	0.206	25.9
130	.162	23.1
120	.120	21.5
110	.135	14.1
100	.113	9.6

The values of i_m from Table I plotted against θ fall on a straight line whose intercept on the i_m axis is $\theta = 77°$. At any

FIG. 7.



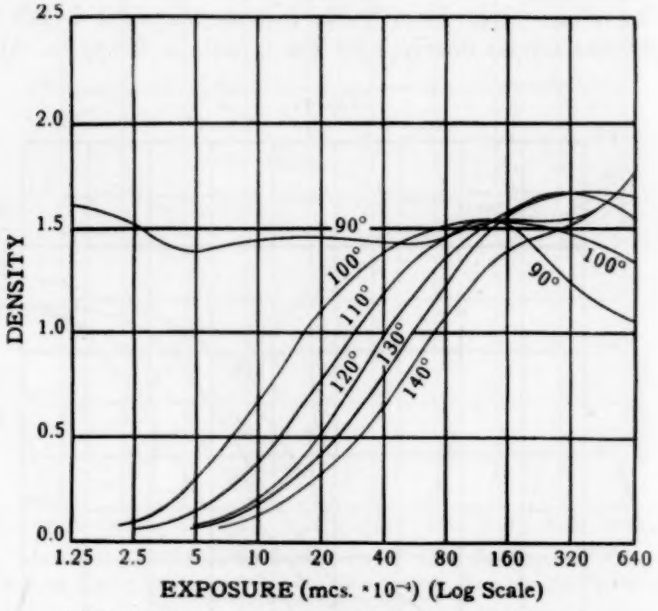
Effect of etching at 130° F. for the number of minutes indicated.

lower temperature i_m should be negative. This conclusion is substantiated by Curves A of Fig. 10. These curves are of plates that were not etched in the usual sense of the word, but were washed for the number of minutes indicated. The action that occurs might, of course, be considered etching at a low temperature (72°). Evidently i_m, which is practically attained in

210 minutes, is negative. The two-minute and four-minute curves of Fig. 6, which are of plates etched at 90°, also exhibit negative inertia resulting, however, not from too low a temperature, but from too short a time. This phenomenon of negative inertia is probably due to a reduction of the permeability of the gelatin to dye by long exposure.

In choosing four minutes and 130° for our standard etching conditions, we compromised between low inertia (hence short

FIG. 8.

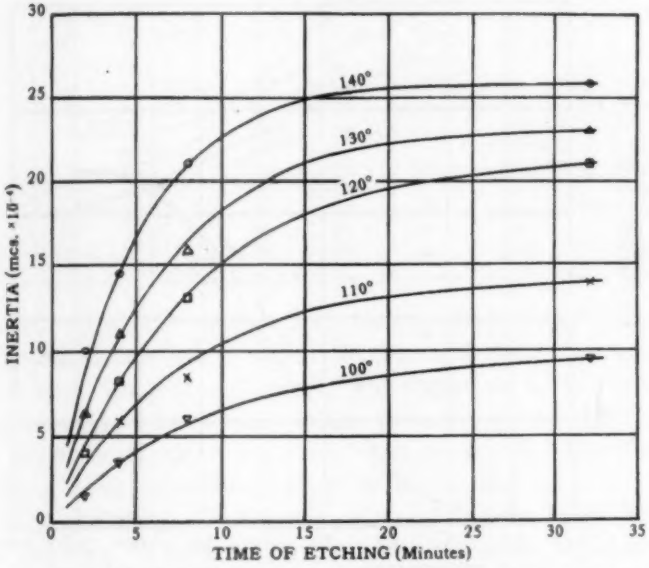


Effect of etching for four minutes at the temperatures indicated.

exposure time), certainty of satisfactory etch, and short etching time. Unfortunately, slight variations from these conditions result in comparatively large variations in the inertia of the plates as the curve of Fig. 9 is rising rapidly. Nevertheless, the maximum variations need not be more than ± 5 sec. and ± 2° F., and the variations in inertia thus introduced are negligible compared with those introduced from other sources (see Sec. 8 and Fig. 14). In the case of two-color transparencies, moreover, variations from this source can be minimized by etching both plates of a pair together.

(6) *Washing Time.*—A very slight increase of inertia is produced by increasing the time of washing from five minutes to 1300 minutes, as Curves *B* of Fig. 10 show. Curves for 32 minutes and 210 minutes, omitted for the sake of clearness, lie in order between the two presented. This indicates that the increase of inertia is not due to experimental error, but is due to the

FIG. 9.



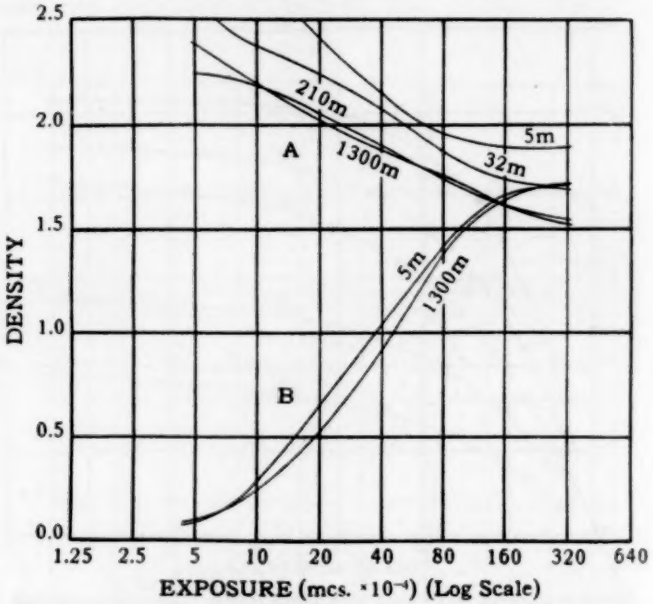
Variation of inertia with etching time for the etching temperatures indicated.

prolongation of the time of washing. The change is so slight, however, that in practice it is negligible.

(7) *Dyeing Conditions.*—The most important precaution to be observed in dyeing is to allow the entire matrix to become saturated in order that the necessary density range may be attained. That is, a short dyeing time is not sufficient to allow the thick parts of the matrix to become saturated, as shown by Fig. 11. The low densities should not change as the time is increased because a short dyeing time should be just as effective in saturating the thinner portions of the matrix as a longer one. Undoubtedly the slight variation exhibited is due to experimental error since it seems to be unsystematic.

The addition of a comparatively small amount of acetic acid to the dye increased the concentration of dye in the gelatin and hence gamma, but also increased the time required for complete dyeing. The addition of 0.0001 per cent. of glacial acetic acid produced no perceptible effect, but 0.01 per cent. increased gamma so much that the high densities became unreadable. When the

FIG. 10.



Effect of time of washing in water at about 72° F. for the number of minutes indicated. *A*, plates fixed and washed as soon as exposed (not etched). *B*, plates treated as usual.

dye concentration was reduced to 0.01 per cent. so that gamma was approximately what it was before, the curves of Fig. 12 were obtained. Comparison with Fig. 11 will show clearly the retarding effect of the acid. This effect increases as the acid concentration increases. For example, a matrix dyed 20 hours in a bath containing 0.5 per cent. acid and 0.01 per cent. dye had a density of 1.2 at an exposure of 20×10^4 mcs., but no greater density beyond that. In view of these results, it would seem advisable to use plain dye without acid despite the saving in dye that might be effected by the use of acid. Moreover, a large amount (*e.g.*, 0.5 per cent.) of acid causes the surface of the

matrix to roughen, and enough acid to produce a perceptible effect seems also to conduce to erratic dyeing.

(8) *Reproducibility.*—As an indication of the reproducibility to be expected in practice, the curves of plates made under similar conditions (Table II) are replotted in Fig. 14. The variations

TABLE II.

Figure.	Curves.	Sensitizing.		Drying.		Minutes between Sensitizing and Exposing.	Date.
		Time.	Temp.	Temp.	Hum.		
1	*A*	5 min.	69°	77°	56%	60	Aug. 16
	B	9	69	77	56	50	Aug. 16
2–4	*A*	5	62	74	44	35	June 2
6–8		5	58	—	—	<14 hrs.	Apr. 27
10		13	70	77	56	60	Aug. 16
11		5	70	77	56	40	Aug. 16
12		5	73	77	56	40	Aug. 16
13	*A*	6	64	77	58	45	July 28
	B, C	5	61	77	58	40	July 28

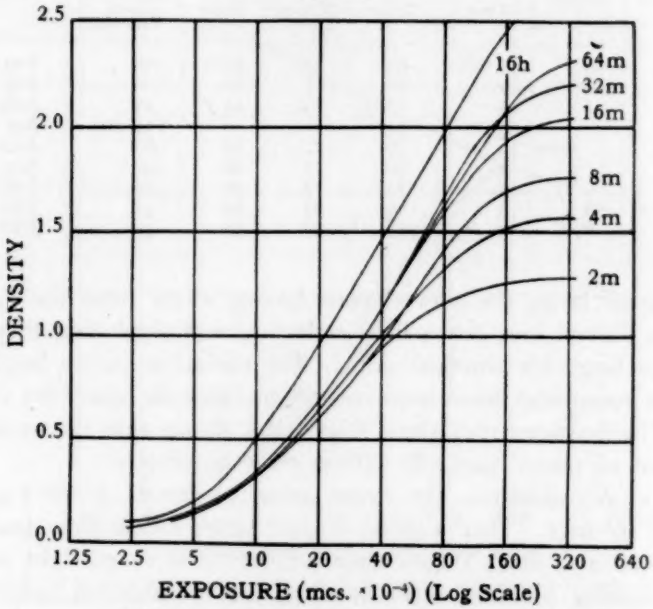
are rather large, the slowest plate having about twice the inertia of the fastest one, but a little reflection will show that they are not too large for practical work. The variations in the humidity of the room may have been enough to cause the observed variations in characteristics since Eder [4] has shown that the moisture content of plates markedly affects their sensitivity.

(9) *Sensitivity.*—The mean value of inertia from Fig. 14 is 6×10^4 mcs. This is about 6×10^5 times slower than amateur film and 400 times slower than a representative gaslight paper. For making pictures, unfortunately, the illumination cannot be made great by using a large number of lights placed near the printing frame because the light source must subtend a small angle at the frame to make spreading in the glass negligible. An arc with ½" carbons placed 50 cm. from the frame was found to be a satisfactory source and the exposures were only a few minutes long. A feature which compensates for the long exposure is the convenience of being able to work in a light room. Most of the work can be done in a room artificially lighted to an ordinary level. Even the exposures can be made in such a room.

(10) *Factors Governing Latitude.*—The chief factor governing the latitude of a material of given thickness is the optical

absorption of the material during exposure. Fig. 13 shows this. Here Curve *B* is of a plate sensitized in a bath to which was added 0.1 per cent. of acid scarlet. (This dye was chosen simply because it was at hand.) Even at 640×10^4 mcs. this curve has not developed a shoulder, whereas Curve *A* developed a shoulder at 120×10^4 mcs. The inertias are the same, however, so the latitude of *B* is greater than that of *A*. Of course the gamma of

FIG. 11.



Effect of time of dyeing in 0.5 per cent. acid scarlet.

B is lower than that of *A* because of the increase in the value of a in equation (9), but this can be overcome by dyeing the matrix in a more concentrated solution to increase the value of b.

All these effects of a light restrainer can be shown to follow from the theory already developed. Let us suppose that on a certain sensitometric strip, the absorption of which is a, a certain exposure $E_n - E$ is just sufficient to make the isosclerotic surface coincide with the free surface of the gelatin. Then at longer exposures E_{n+1}, E_{n+2}, . . ., the relief will not be any higher because there is no more gelatin present to be hardened. There-

fore, the characteristic curve will have a sharp shoulder at E beyond which it will be horizontal. The maximum density is

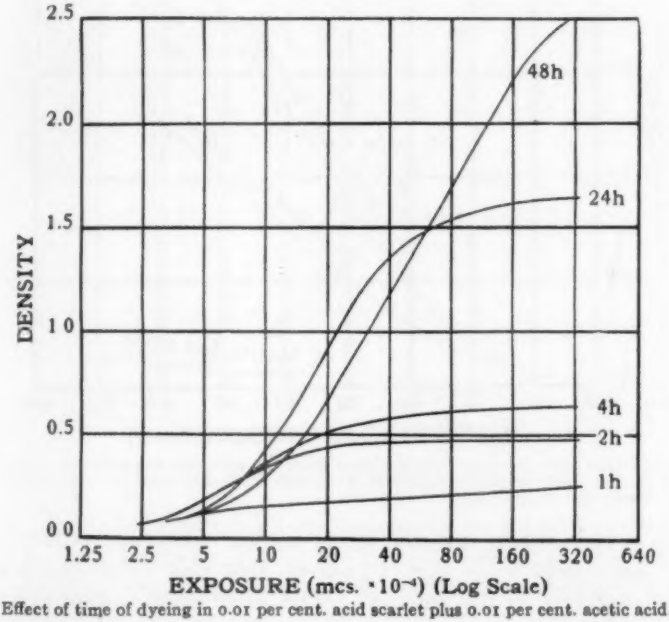
$$D_{max} = \frac{b}{a_1} (\log E_n - \log E') \qquad (12)$$

and is a constant if b and E' are unchanged. Now if the absorption is increased from a_1 to a_2 by a light restrainer in the sensitizer,

$$D_{max} = \frac{b}{a_2} (\log E_{n+1} - \log E') . \qquad (13)$$

Evidently the position of the shoulder has been moved to the

FIG. 12.



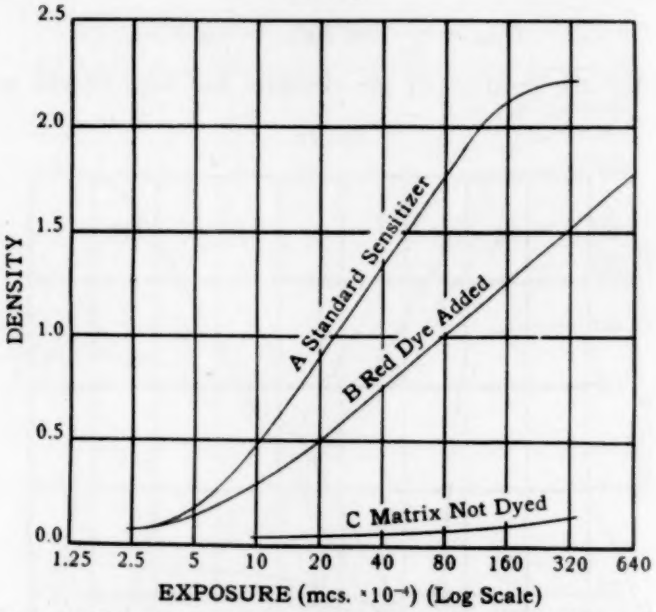
Effect of time of dyeing in 0.01 per cent. acid scarlet plus 0.01 per cent. acetic acid.

right from E_n to E_{n+1} as shown in Fig. 13. At the same time, the restrainer does not increase the inertia of the plate because the light producing the lower densities does not penetrate the gelatin deeply enough to be greatly affected by the restrainer. Thus the latitude is increased.

In order to be useful a material must possess a certain latitude and therefore must have some restrainer incorporated in it. In

the carbon process the pigment forming the finished picture acts as the restrainer. In the present case the silver halide in the emulsion of the plate serves the purpose. It is in particles, however, and causes scattering, so the addition of a dye should increase the resolving power of the plate by preventing the light from penetrating deeply. Also at long exposures some of the

FIG. 13.



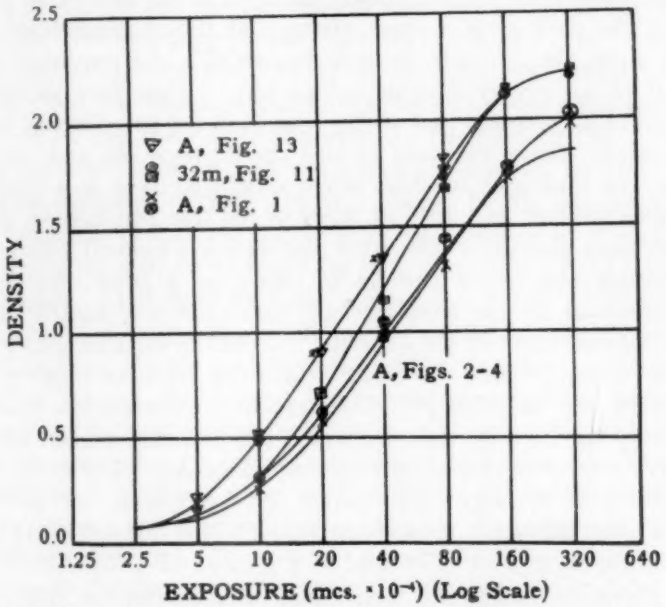
Effect of a light restrainer. *A*, sensitizer made according to standard formula in text. *B*, same sensitizer with 0.1 per cent. acid scarlet added. *C*, matrix made as usual but not dyed to show density due to actinically reduced silver.

halide is reduced to metallic silver which cannot be removed by hypo, but Curve *C* of Fig. 13 shows that this silver contributes almost nothing to the density. The bichromate solution itself, being yellow, acts as a restrainer but only to a slight extent in comparison with the halide. Fig. 1 shows that diluting it to twice its volume produces very little effect.

In this connection, it is important to note that Richter [3] prepared plates with a latitude of 160 by using a sensitized gelatin in which he incorporated a black pigment. The plates used in the present investigation had a latitude of 16. Probably the great latitude of Richter's plates was due to the strength of his

restrainer, but perhaps partly to the thickness of his gelatin. If the location of the shoulder depends upon the coincidence of the isosclerotic surface with the free surface of the gelatin, as has been assumed above, a thick coating obviously would have a great latitude. This would not be the case, however, if the location of the shoulder depends upon the minimum exposure neces-

FIG. 14.



Curves copied from preceding figures to indicate the reproducibility to be expected when the temperature and humidity of the room are not controlled.

sary to produce some super-hardening of the gelatin competent to prevent absorption of dye by the latter. Any such super-hardening would occur at the glass surface where the exposure is greatest, and while an increase in the thickness of the gelatin would allow the isosclerotic surface to proceed farther from the glass, the surface of super-hardening would follow it and tend to prevent an increase in the thickness of gelatin available for being dyed. That is, the dyed matrix would be bounded on the front by the isosclerotic surface and on the back, not by the glass, but by super-hardened gelatin. We do not know that such a phenomenon takes place, however, and mention it merely as a possibility.

IV. APPLICATION TO TWO-COLOR PICTURES.

Since one of the principal uses of bichromated gelatin probably will be for two-color pictures, an outline of what we found to be a satisfactory method of applying it to this purpose may be appropriate.

Before any pictures are attempted, certain further data must be secured so that a standard procedure may be adopted. First a piece of film should be exposed in strips in the camera by pushing in the dark slide a short distance at the expiration of two, four, eight, etc., seconds, the camera, with its lens removed, being aimed at an evenly illuminated surface. This film should be treated in all respects just as the negatives for the pictures are to be treated. Some matrices of this should be made and cut into strips and then each of these strips should be dyed in a different concentration of dye, half of them in red dye and half in green. From these should be selected a pair which is neutral throughout its length and has a gamma of unity or a little more when the abscissas of the characteristic curve are the logarithms of the exposure times of the *negative*. (That is, the abscissas of the curve of the positive combination are the same as those of the curve of the negative.) Of course this examination must be made by the kind of light by which the pictures will be viewed.

We used commercial panchromatic film developed in an elon-hydrochinon developer that would give a gamma of unity in about four minutes. Since our subjects did not have excessive brightness ranges we developed to a gamma of unity. Had they had excessive ranges we would have had to develop them to a lower gamma and then increase the dye concentration to produce a higher transmission range in the positive without exceeding the exposure range of the latter. It is well not to make the gamma of the negative too low because then they are likely to be unevenly developed.

The choice of dyes depends upon the colors to be reproduced, but a red and a green seem to give the best all around results. The dyes can be selected by making matrices of the negative that has been exposed in strips as described above, dyeing them in the dyes being examined, and pairing them at right angles to each other in turn. Such a pair exhibits all the colors that can be reproduced by the corresponding dyes since the former are uniquely determined by the latter.

The choice of filters depends upon the predominating colors of the subject. We have found four to be enough to try for most subjects, Wratten Nos. 25 (*A*) and 22 (*E2*) for the red, and Nos. 60 (*P*) and 45 (*H*) for the green.

In some special cases the method of selecting dyes and filters outlined above can be simplified and the results improved at the same time. Many microscopic subjects, histological specimens in particular, can be treated best by being photographed through filters complementary to their stains. The resulting matrices should be dyed so as to simulate the stains of the section, but the simulation need not be very close since the only purpose of the color is to differentiate the parts of the section. This particular case is more extensively discussed by Mees.[1]

The exposure of each negative should be the minimum that will keep the picture on the straight-line portion of the characteristic curve in order to make the exposure times of the positives reasonable. To determine the exposures of the positives, the density of the image of a white portion of the subject on each of the negatives should be measured. The exposure through the negative having the densest image can be computed from the curves of the positive and the negative materials. The exposures through the other negatives can then be computed from the consideration that the white portion must be reproduced neutral. Of course no combination of dyes used for the picture of a histological specimen may be neutral. The white parts of the section are simply the clear areas, however, so the exposures of the positives can be made short enough to place these areas on the toe of the curve and hence be so thin that they appear clear.

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A comprehensive review of the various bichromated gelatin processes can be found in Wall's "History of Three-color Photography," especially in Chapter XI.

[1] *Brit. J. Phot.*, Col. Sup., **12**, 1918, p. 1. Reprinted in "Photomicrography," a pamphlet issued by the Eastman Kodak Company.

[2] JOUR. FRANK. INST., **189**, 1920, p. 469, and **190**, 1920, p. 39.

[3] *Zeits. Wiss. Phot.*, **23**, 1925, p. 61.

[4] *Inland Printer*, **75**, 1925, pp. 594 and 772, and **76**, 1925, p. 91. This series of papers should be consulted by anyone planning to use the process extensively because it contains much information that is valuable in suggesting precautions to be taken.

The Salton Sea, California. (Report and Map Released by the Geological Survey for Inspection.)—Lands which have been flooded during periods of high water may usually expect quick relief when the rivers recede. However, where the flooded lands are below sea-level a most unusual condition is created.

During 1907 heroic measures finally stopped the overflow of the Colorado River into Imperial Valley, Calif., but not until a lake, known as Salton Sea, had been formed, covering 330,000 acres to a maximum depth of 79 feet, containing enough water to cover 16,000,000 acres to a depth of one foot. As the surface of this lake was 194 feet below sea-level, there was no place to which the water could drain, and were it not for nature's pump—evaporation—the lake would probably be nearly the same to-day as it was in 1907. As a result of evaporation, however, the lake receded until by 1920 it covered only 170,000 acres. Since 1920 the lake has been fairly stable, due to inflow of natural drainage and a large volume of seepage and waste water from irrigated lands in Imperial Valley, but what of the future? As the lands under and around the lake have economic value, it has seemed advisable to make some sort of a prophecy as to what future conditions are likely to be.

During 1925 the Interior Department, through the Geological Survey, made a topographic survey of the Salton Sea, and during 1927 a study of the problem. A report has recently been prepared by George F. Holbrook, an assistant engineer of the Geological Survey, which contains a brief history of Salton Sea, describes the conditions which surround the lake, and concludes that in order to evaporate the amount of water that may be wasted into Salton Sea under conditions of ultimate irrigation development, an average water-surface area of 239,000 acres will be necessary. This corresponds to a lake surface of 228 feet below sea-level or some 20 feet higher than the present lake surface. The report will not be published but, with the maps, may be examined in manuscript form at the office of the Geological Survey in Washington, D. C.

Blinding Smoke.—According to LEIGH F. J. ZERBEE (*Chem. Warfare*, 1927, 13, 196–197), blinding smoke is smoke delivered on or immediately in front of the enemy by friendly artillery or other projecting apparatus or by airplanes. When fire with ball ammunition is directed at a line of silhouette targets at a range of 300 yards, approximately 55 per cent. of the shots hit the target. When a smoke screen is set up immediately in front of the targets, and firing is repeated, about 12 per cent. of the shots hit the target. When the smoke screen is placed immediately in front of the firing line, and firing is again repeated, approximately 4 per cent. of the shots hit the target. These results demonstrate that, when blinding smoke is used by the offense, the fire of the offense is three times as effective as the fire of the defense. J. S. H.

MODERN RESEARCH ON THE STRUCTURES OF METALS.*

BY

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THE work of an industrial research laboratory falls naturally into three divisions: (1) Getting the factory out of manufacturing difficulties; (2) development of new products and processes; (3) search for new scientific principles which may be applied in industry. All three of these are represented in any account of research and development work in X-rays.

(1) SOLUTION OF FACTORY DIFFICULTIES.

Probably the first work which used X-rays in an effort to solve factory problems was done in the Research Laboratory of the General Electric Company, at Schenectady. While a large steel casting several feet in diameter and about a half an inch thick was being machined to size in the factory a tiny crack was found in the metal. The casting was taken to the laboratory and X-ray pictures were taken. These pictures showed a large hole in the inside of the metal. The spot indicated by the pictures was punched out and the hole was thus exposed to view. The use of X-rays in work of this sort was very expensive, so that soon other methods of testing were developed for smooth-faced metal, which were just as good and considerably cheaper. The X-ray inspection of castings was therefore discontinued at the General Electric Company, but it has since been taken up by the United States Government at the Watertown Arsenal, where an investigation was made of foundry processes. Occasionally, too, the arsenal has made X-ray pictures of special castings where considerations of human safety have justified the high cost of such work. The most outstanding example of this was the X-ray inspection of some steam fittings for a new high-pressure steam line of the Boston Edison Company.

Shortly after this, efforts were made by many industries to use X-rays in the routine inspection of their products. In some

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cases the cost was too high and the attempts were abandoned. The less dense the material to be inspected, the cheaper the method was and the more likely it was to survive. One shoe company developed an apparatus for examining every pair of shoes which they made, in order to make sure that no nails stuck through the shoes. The General Electric Company, in its Research Laboratory, developed an apparatus for the cheap and rapid X-ray inspection of mica. Every large direct-current motor and generator and every field-exciter for alternating-current generators has mica insulation between the commutator bars. This insulation is made by pasting together thin sheets of mica to make slabs of the proper area and thickness. Some of the mica is mined in Canada and some in India, and during transportation, in spite of all precautions, impurities get in. These impurities range all the way from splinters of wood from the crates to strands of wire. Even hairpins and tinfoil are found at rare intervals in the X-ray inspection.

The X-rays not only serve to show the presence of foreign substances in the finished product, but also act as a sort of micrometer for measuring the thickness of the mica contained in the slab. This is made possible by the fact that the material used for sticking the thin sheets of mica together is much more transparent to X-rays than the mica itself. If, in the course of manufacture, some portion of the slab does not receive its full quota of mica, the hole may become filled with the sticker and thus appear, on casual inspection, to be of the proper thickness. But the X-ray examination shows the defect on a fluorescent screen as a bright spot. In this way it is possible to measure within about two thousandths of an inch the total thickness of mica present. Such an X-ray inspection tends to insure the reliability of our electric power supply, and contributes to the high quality of the modern electric motor.

(2) AIDING DEVELOPMENT WORK.

X-rays are useful, too, in the development of new products and processes and in the standardization of existing satisfactory products. As might have been expected from what has already been stated, the radiography of metal castings has made it possible for the Watertown Arsenal to improve the foundry practice of the arsenal. However, most of the development work in

which X-rays have played a part is of quite a different sort. Two illustrations will serve to show the diversified character of this sort of X-ray work. In the manufacture of electric lamps and radio tubes, the diameter of the tungsten wire is often so small that it cannot be measured with sufficient accuracy with micrometer calipers. Instead, a known length is weighed on a microbalance, the volume is computed from the weight of the wire and the density of tungsten, and the diameter is computed from the volume and the length. In the standardization of electron emission data at the General Electric Company, it became necessary to know the surface area of the tungsten wires to a higher degree of precision. This required a determination of the density of tungsten to ten times the accuracy known at that time. The necessary precision was obtained by measuring the lattice parameter of crystals of tungsten. Again in a study of some tungsten filaments it became desirable to detect the presence of W_2C. The crystal structure of the carbide was determined and certain of its properties were predicted.

(3) DISCOVERY OF NEW FACTS.

It is in the discovery of new facts on which to base future factory processes that we find the greatest usefulness of X-rays. Practically all work of this sort depends upon the measurement of interatomic distances. These distances are so small that they cannot be measured directly. They are of the order of 10^{-8} cm. By using X-rays of known frequency it is possible to use an X-ray diffraction apparatus as a micrometer for measuring these extremely small distances. The technique has been refined so that such measurements may be made easily with an accuracy of one part in a thousand. This sort of apparatus, which was developed at the Research Laboratory of the General Electric Company, is now in use in the School of Chemistry and Physics at Pennsylvania State College in investigating the properties of metals and their alloys. By measuring these minute distances, it is already possible to predict some of the mechanical properties of metals, and to tell what happens when they form alloys. It is possible to show why copper is more ductile than iron, and why iron is more ductile than arsenic. Similar measurements made on tungsten, the material of which lamp filaments are made,

make it seem that the Coolidge process now in use is the only process by which it can be made into a ductile wire.

By means of apparatus of this sort it is possible, too, to study the effect of mechanical working of metals on the preferred orientation of the crystals in the metal. When a crystal of a metal is distorted, as by rolling, it is natural to assume that the layers of atoms which glide over each other are those which have the greatest interplanar spacings in the crystal. A study of the angle which this spacing takes with relation to the direction of rolling is of the highest importance in the study of the properties of rolled sheets of metal. An example of such work is to be found in a preliminary study of tungsten foil which is to be given at the next meeting of the American Physical Society.

A study has been made of the mechanism of melting which serves to correlate the melting-point with the total expansion of the metal from absolute zero to the melting-point.

Studies of alloys are of increasing importance, especially when the study has to do with alloys of high purity. It has been found possible to make wires of certain alloys in a state of extreme purity by never allowing the metals to become melted even when making the alloy. This work is being done at Pennsylvania State College in coöperation with the Research Laboratory of the General Electric Company.

The reason for the reduction in electrical conductivity, the general increase in hardness and strength, and the decrease in ductility of alloys seem now to be pretty well established. Some of these points may be illustrated by a study of carbon in iron.

Below 900° C. (1650° F.) pure iron exists as "alpha iron." In each crystal in the metal the atoms are arranged in a definite configuration which is called a "body-centred cubic lattice." In order to visualize this, let us imagine a three-dimensional lattice work built up of geometrical lines in such a way that they outline a group of cubes, all of equal size and all in close contact with their neighbors. Now let us imagine an atom of iron at each of the intersections of these lines. Each of these will therefore lie at the meeting point of eight of the imaginary cubes. Imagine, besides, an additional iron atom placed at the centre of each of these cubes. This whole configuration is, then, a "body-centred cubic lattice," and the structure is called a body-centred cube. Each of the cubes in the imaginary framework of lines is called a

"unit-cube." It is customary among crystallographers to picture only one of these unit-cubes, leaving it to the imagination of the reader to extend the lattice-work for an indefinite distance in all directions. In alpha iron the side of the unit-cube is 0.000,000,028,55 centimetre (0.000,000,011,23 inch). Between 900° C. and 1400° C. (1650 to 2550° F.) pure iron exists as "gamma iron." Each unit-cube then has an iron atom at each corner and one at the centre of each face. This structure is called face-centred cubic. The steels have similar structures, but the transition temperatures are different. There is no X-ray evidence of so-called "beta iron." Above 1400° C. (2550° F.) iron exists as "delta iron," which has a body-centred cubic structure like alpha iron.

Just as a regularly planted potato patch appears to have rows in different directions, depending upon the direction from which it is viewed, in the same way a crystal has planes of atoms in different directions through the crystal. The distance between adjacent planes will depend upon the direction of those planes in the crystal. In a body-centred cube the planes which have the greatest spacing are those which contain a cube-edge and a face-diagonal. This plane is technically known as a dodecahedral plane or as a 1 1 0 plane.[1] When alpha iron is mechanically worked these 1 1 0 planes tend to slide over each other. In the language of the metallographers, those planes are "slip planes." These slip planes are held together by the attractive forces between the atoms in each plane and the atoms immediately adjacent in the planes on each side. A study of a model of a body-centred cubic lattice shows that each atom in any given 1 1 0 plane is held principally by two atoms in the adjacent 1 1 0 plane on one side

[1] There are several ways in which the atomic planes in crystals might be named. One of the most obvious of these is to name the plane by its intercepts on the axes of reference. The mathematics of crystal structure requires, however, the constant use of the reciprocals of these intercepts. For this reason it has become customary to name the atomic planes in terms of the smallest integers which are proportional to the reciprocals of the intercepts of the planes on the axes of references. Thus, the family of parallel planes whose intercepts are $1\infty\infty$, $2\infty\infty$, $3\infty\infty$, etc., are all called 1 0 0 planes; in a cubic crystal they are the atomic planes parallel to the cube face. Similarly the family of parallel planes whose intercepts are $\frac{1}{2}\ \frac{2}{3}\ 1$, $1\ 1\frac{1}{2}\ 2$, $1\frac{1}{2}\ 2\ 3$, etc., are called 4 3 2 planes. These integers are ordinarily called "Miller indices." Their use has practically displaced all other methods of naming the various possible planes of atoms in crystals.

and by two other atoms in the adjacent 1 1 0 plane on the other side.

In gamma iron the planes which have the greatest spacing are those which contain two face-diagonals. Such planes are called octohedral or 1 1 1 planes. In a face-centred cubic crystal, each atom in a given 1 1 1 plane is held principally by three atoms in the adjacent 1 1 1 plane on one side and by three other atoms in the adjacent 1 1 1 plane on the other side. This means that the slip planes in gamma iron are much more firmly tied together in the direction perpendicular to slip than are the slip planes in alpha iron, and the metal can be much more drastically worked. This is one of the reasons why steel is rolled above red heat.

It has been suggested by P. Ludwik that, in some cases at least, the effect of alloying elements is to introduce into the crystal structure atoms which are so large as to mechanically interfere with slip in much the same way that a rough spot on a shaft serves to interfere with the motion of the shaft in its bearing. In the case of carbon in steel there is still another possibility. Westgren has shown that in gamma iron most of the carbon lies between the 1 1 1 planes, but that in alpha iron most of it lies in the 1 0 0 planes. The crystal structure of alpha iron is such that there are natural tunnels running through each crystal parallel to each of the faces of the cube. These tunnels each have a cross-section as large as that of an iron atom. Half the total volume of a crystal of alpha iron is taken up by these tunnels. It is in these tunnels that most of the carbon in quenched steel is to be found. Although it has never been proven experimentally, there are good theoretical reasons for believing that the carbon "atoms" lie very near to the points where these tunnels intersect each other. There is also good reason for believing that at room temperature these carbon atoms are rather tightly fastened to some of the adjacent iron atoms. In this way the 1 1 0 planes in steel are bonded together more tightly than in pure iron, thus largely accounting for the greatest strength of martensitic [2] steel over pure iron. A somewhat similar bonding action may be used to account for the strength of austenitic steel.

[2] This is the usual condition of hardened stool steel. Austenitic steel can be obtained by very drastic quenching of high-carbon and alloy steel from a high temperature. It is considerably "softer" than martensitic steel.

When it is remembered that in 0.17 per cent. steel the carbon atoms are, on the average, only five atomic diameters apart, it is easy to see why a small percentage of carbon by weight can exert such a profound influence on the properties of steel.

It is well known that carbon can migrate readily through alpha iron. If it were not for such migration it would not be possible to change martensitic steel into sorbitic steel by heating it. It is believed that most of this migration takes place through the tunnels in the alpha structure. We may assume that if we had a perfectly homogeneous distribution of carbon in alpha iron, each carbon atom would be attached to adjacent iron atoms to form a " molecule " of Fe_3C. Such a picture is consistent with the known facts in the case of other compounds of carbon. If, now, this imaginary specimen of alpha iron is heated, each carbon atom would tend to move in one direction or another through the tunnels, breaking its union with one iron atom to form a new union with the next iron atom along its path. If two carbon atoms happen to move towards each other so that they find themselves in the same relative positions to each other and to the surrounding iron atoms that they would have in cementite (Fe_3C), the chance of their breaking away and migrating further would be greatly lessened. If a third carbon atom joins this pair, the chance of their migrating apart would be still less. The tendency in a carbon steel, heated below the critical range, to allow carbon to migrate, is therefore always to form aggregates of Fe_3C. In gamma iron the carbon seems to be in solution in the iron. The face-centred cubic structure of gamma iron does not have the tunnels which characterize alpha iron and each carbon atom seems to lie at the centre of a tetrahedron of iron atoms. If a specimen of gamma iron containing carbon is lowered to the transition temperature for alpha iron and is then cooled slowly, there is plenty of chance for the migration of atomic carbon as described above, and the alpha iron contains pearlite, which may be regarded as Fe_3C or at least as an intimate mixture of Fe and Fe_3C. If, instead, the specimen is cooled very rapidly, as by quenching, there is little chance for migration and martensite is formed in the alpha iron. If this is tempered, more opportunity is given for the migration of atomic carbon. This results in larger aggregation of Fe_3C in alpha iron. If only a short time or low temperature is allowed

for tempering, the migration is only sufficient to produce aggregates of Fe_3C of colloidal size, thus giving troostite. At longer times or higher temperatures the aggregates of Fe_3C are larger, thus giving sorbite. Still longer heating produces the massive (spheroidal) condition of Fe_3C known as cementite.

In gamma iron the possible spaces in which atomic carbon may exist have a configuration which is closely related to the configuration of carbon atoms in a crystal of graphite. If two atoms of carbon in gamma iron migrate so as to occupy the same relative positions to each other that they would have in a crystal of graphite, their tendency to further migration will be decreased. This tendency will be further lessened by the chance arrival of a third atom of carbon in the position which it would have in graphite. The chance that such configuration will occur is increased as the number of carbon atoms in the iron is increased. For this reason it is easy to obtain "platelets" of graphite by long annealing of high-carbon steel.

ASYMPTOTIC SOLUTION OF HEAVISIDE'S FRACTIONAL OPERATORS.

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ON page 40, Vol. II, of Heaviside's "Electromagnetic Theory" is given the solution of a problem involving an infinitely long "ideal" cable connected to a battery through a condenser. On page 42 is given a similar problem where instead of a condenser a coil is used. In both cases operational solutions occur involving fractional exponents of p.

Heaviside proceeds to expand them in powers of $\frac{1}{p}$ and p. The expansions in powers of $\frac{1}{p}$ give convergent solutions which are conveniently used for small values of t. The expansion in powers of p gives the asymptotic series, which may or may not be the complete solution. The asymptotic solution is subject, of course, to an error not greater than the smallest term in the series for any given value of the variable.

In the first problem the asymptotic series is the complete solution, in the second an important term is added. Heaviside gives an explanation of the reason for adding the second term in the end of Vol. II. This explanation is very difficult to understand and as given by him is not very satisfactory.

J. R. Carson has shown that the convergent and asymptotic solution can be obtained by the use of definite integrals. Unfortunately, however, these integrals are frequently difficult to evaluate.

The present paper shows how to obtain the asymptotic solution by means of the expansion theorem in a strictly operational way. Incidentally it has recently come to our notice that Mr. W. O. Pennell has reached the same method.

Statement of Theorem.—Any operator of the type

$$\frac{\phi(p)}{x(p)}1^{1} \tag{1}$$

where $x(p)$ is of a form which can be rationalized to contain only integral powers of p, and $\phi(p)$ contains integral and fractional powers of (p), the highest degree of (p) in the numerator being less than the highest degree of (p) in the denominator when the fraction is rationalized, has for its asymptotic solution the asymptotic series obtained by division in rising powers of (p) and an additional term. This additional term is obtained by solving the rationalized operational equation in the usual way by the expansion theorem and retaining only the real part of the result.

The majority of the operators of this type considered by Heaviside are of the form

$$\frac{Y(p)}{1+(ap)^{\frac{n}{2}}}E1 \tag{2}$$

where (n) is an odd integer and $Y(p)$ contains powers of (p) or $p^{\frac{1}{2}}$. The asymptotic series is found as stated above.

The additional term is the real part of the result of applying the expansion theorem to

$$\frac{\left[1-(ap)^{\frac{n}{2}}\right]Y(p)}{1-(ap)^{n}}E1. \tag{3}$$

In determining the roots by equating $z(p)=0$ it must be noted that the nth roots of $1-(ap)^{n}=0$ are

$$\frac{1}{a}\underline{\lfloor 0}, \frac{1}{a}\underline{\left| \pm\frac{2\pi}{n}\right.}\cdots\frac{1}{a}\underline{\left| \pm(n-1)\frac{\pi}{n}\right.}.$$

Any imaginary terms are rejected.

The following three methods of proof will be given:

(1) The general solution of (1) is obtained by the use of Duhamel's definite integral from zero to time (t). The method

[1] 1 denotes Heaviside's unit function,

$$\begin{aligned} 1&=0 \quad t<0\\ 1&=1 \quad t>0\\ 0\underline{\leq}1\underline{\leq}&1 \quad t=0 \end{aligned}$$

is strictly mathematical. The range of integration is broken up into two parts, giving an integral from zero to infinity, which is the additional term, and one from (t) to infinity, which expands by parts into the asymptotic series.

(2) The second method used is to note that the difference between the convergent series and the asymptotic series is of the form $\varepsilon Ce^{\alpha_n t}$, where α_n is a root of the rationalized determinantal equation. The value of C is determined by calculating numerically the value of the different series at a few points. It might also be determined by other methods.

(3) A specific example is given. The solution for a finite line is derived, and the limit taken as the length of the line approaches infinity. The result for both the convergent and asymptotic expansion is checked with the values obtained by Heaviside for the same problem.

Method 1.—Since equation (1) can always be rationalized so that the denominator contains only integral powers of p, we can write the expression in the form

$$\frac{F_1(p) + F_2(p)}{F(p)} \tag{4}$$

where $F(p)$ and $F_1(p)$ contain only integral powers of p and $F_2(p)$ contains fractional powers of (p), the highest degree of (p) in the numerator being less than the highest degree of (p) in the denominator when the fraction is rationalized.

Split expression (3) into partial fractions. The partial fractions can then be divided into two sets, one of which contains only integral powers of p in the numerator (to which the expansion theorem can be applied) and the other set containing fractional powers of p in the numerator. The general form of the latter set can be expressed as

$$\frac{p^r}{p - \alpha} 1 \tag{5}$$

where r is a fraction.

If it is shown, by the definite integral method, that the convergent expansion is the correct solution of the latter, and that the sum of the results obtained by the expansion theorem and

the asymptotic series is also the correct solution, the rule is in general proven for any expression of the type

$$\frac{\phi(p)}{x(p)} \cdot 1$$

where $x(p)$ is of a form which can be rationalized to contain only integral powers of p, and $\phi(p)$ contains integral and fractional powers of p.

If an e.m.f. $E = 0$ $t < 0$, $E = 1$ $t > 0$ applied to any circuit produces a resultant current or e.m.f. at any point equal to $\phi(t)$, then the current or e.m.f. produced by a voltage $E(t)$, where $E(t) = 0$ $t < 0$, and $E(t)$ is some function of t $(t > 0)$, is given by Duhamel's integral as follows:

$$g(t) = E(t)\,\phi(0) + \int_{u=0}^{u=t} \frac{d\phi(t-u)}{dt} E(u)\,du. \qquad (6)$$

In (5) we may divide the fraction into two parts, $\frac{1}{p-\alpha}$ and $p^{r}1$. If we determine the effect of a unit voltage applied to the circuit $\frac{1}{p-\alpha}$, this corresponds to $\phi(t)$.

$$\phi(t) = -\frac{1}{\alpha}(1 - \varepsilon^{\alpha t})$$

$$\frac{d\phi(t-u)}{dt} = \varepsilon^{\alpha(t-u)}.$$

Then writing $p^{r}1 = \frac{t^{-r}}{\lfloor -r}1 = E(t)$ we find for Duhamel's integral

$$g(t) = \int_0^t e^{\alpha(t-u)} \frac{u^{-r}}{\lfloor -r}\,du \qquad (7)$$

$$= \frac{e^{\alpha t}}{\lfloor -r} \int_0^t \frac{e^{-\alpha u}}{u^{r}}\,du. \qquad (8)$$

Assume the real part of α to be positive, then

$$g(t) = \frac{e^{\alpha t}}{\lfloor -r} \int_0^\infty \frac{e^{-\alpha u}}{u^{r}}\,du - \frac{e^{\alpha t}}{\lfloor -r} \int_t^\infty \frac{e^{-\alpha u}}{u^{r}}\,du \qquad (9)$$

and on integrating by parts, and evaluating the integral from 0 to infinity

$$g(t) = \frac{e^{\alpha t}}{\alpha^{1-r}} + \frac{t^{-r}}{\alpha \underline{|-r}} + \frac{(-r)t^{-r-1}}{\alpha^2 \underline{|-r}}$$

$$+ \frac{(-r)(-r-1)t^{-r-2}}{\alpha^3 \underline{|-r}} + \cdots + \int \text{remainder} \qquad (10)$$

$$= \frac{e^{\alpha t}}{\alpha^{1-r}} + \frac{t^{-r}}{\alpha \underline{|-r}} + \frac{t^{-r-1}}{\alpha^2 \underline{|-r-1}} + \frac{t^{-r-2}}{\alpha^3 \underline{|-r-2}} + \text{etc.} +$$

$$\int \text{remainder} \cdot \qquad (11)$$

The first term containing $e^{\alpha t}$ is the result of applying the expansion theorem to equation (5) and the series is the result of using the asymptotic expansion. That (8) gives the correct convergent series solution may be verified by integrating by parts. If the real part of (α) is negative, write (8) as (12).

$$g(t) = \frac{\varepsilon^{\alpha t}}{\underline{|-r}} \int_0^{-\infty} \frac{\varepsilon^{-\alpha u}}{u^r} du + \frac{\varepsilon^{\alpha t}}{\underline{|-r}} \int_{-\infty}^{t} \frac{\varepsilon^{-\alpha u}}{u^r} du \qquad (12)$$

which becomes

$$g(t) = \frac{\varepsilon^{\alpha t}}{\alpha^{1-r}} + \frac{\varepsilon^{\alpha t}}{\underline{|-r}} \int_{-\infty}^{t} \frac{\varepsilon^{-\alpha u}}{u^r} du \qquad (13)$$

and (13) is treated in the same manner as (9).

Since the complex roots, if any, in the original expression (1) are conjugate, if there is a root $p = \alpha \angle \phi$ there is also a root $p = \alpha \angle -\phi$ and hence if $g_1(t)$ obtained from the root $\alpha \angle \phi$ is complex, $g_2(t)$ obtained from the root $\alpha \angle -\phi$ is also complex and conjugate to $g_1(t)$, so that $g_1(t) + g_2(t)$ is real. Hence the result obtained starting from real coefficients is always real.

There is an exception, however, in the case where α is a real negative number. The method used above for obtaining the asymptotic expansion fails and more advanced methods must be used.[2] If the solution is carried through, it is found that there is no term corresponding to the result of applying the expansion theorem, which is wholly imaginary in this case and, according to the rule given, should be rejected.

[2] See Bromwich, "Theory of Infinite Series," second edition, p. 334.

Let us apply the rule to the following problem. A voltage $Ee^{-at}1$ is impressed upon an infinitely long "ideal cable." Required the current at the generator. The operational solution is

$$I_0 = \sqrt{\left(\frac{C}{R}\right)} \frac{p^{\frac{3}{2}}}{p+a} E1. \tag{14}$$

(a) The asymptotic series is

$$-\sqrt{\left(\frac{C}{R}\right)} \frac{E}{\sqrt{\pi t}}\left[\frac{1}{(2at)} + \frac{1\cdot 3}{(2at)^2} + \frac{1\cdot 3\cdot 5}{(2at)^3} + \cdots\cdots\right]1. \tag{15}$$

(b) $Z(p) = (p+a) = 0$ whence $p_0 = -a$

$$\frac{Y(p)}{p\dfrac{dZ}{dp}} = p^{\frac{1}{2}}.$$

hence the result of the expansion theorem becomes

$$j\sqrt{\left(\frac{C}{R}\right)} \sqrt{a}\, e^{-at}1 \tag{16}$$

and the complete solution is

$$I_0 = -\sqrt{\left(\frac{C}{R}\right)} \frac{E}{\sqrt{\pi t}}\left[\frac{1}{(2at)} + \frac{1\cdot 3}{(2at)^2} + \frac{1\cdot 3\cdot 5}{(2at)^3} + \cdots\cdots\right]1$$

$$+ j\sqrt{\left(\frac{C}{R}\right)} a\, e^{-at}1. \tag{17}$$

The remainder term is imaginary, and should be rejected.

Mr. J. R. Carson has found a solution for this problem, using integral equations, and obtains the asymptotic expansion in a different manner. By so doing he finds the asymptotic series of (14) to be the complete solution. We must therefore add the real part of (16) to the asymptotic series to find the solution (I_0). For this problem the real part of the remainder is zero, but if we had had $p^{\frac{1}{9}}e^{-at}1$ the real part of the remainder to be added would be $a^{\frac{1}{9}}e^{-at}\cos 20°$. This has been verified for a large number of similar problems, including $p^{\frac{1}{4}}$, $p^{\frac{3}{4}}$, $p^{\frac{8}{9}}$, operating on $e^{-at}1$.

Second Method of Proof.—If we expand convergently

$$\frac{1}{1+(ap)^{\frac{n}{2}}}=\left[\frac{t^{\frac{n}{2}}}{\left\lfloor\frac{n}{2}a^{\frac{n}{2}}}-\frac{t^{n}}{\lfloor n\,a^{n}}+\frac{t^{\frac{3n}{2}}}{\left\lfloor\frac{3n}{2}a^{\frac{3n}{2}}}-\cdots\right.\right]1 \quad (18)$$

and expanding divergently

$$\frac{1}{1+(ap)^{\frac{n}{2}}}=\left[1-\frac{a^{\frac{n}{2}}t^{-\frac{n}{2}}}{\left\lfloor-\frac{n}{2}}+\frac{a^{n}t^{-n}}{\lfloor-n}-\frac{a^{\frac{3n}{2}}t^{-\frac{3n}{2}}}{\left\lfloor-\frac{3n}{2}}\cdots\cdots\right.\right]1. \quad (19)$$

Testing that the series in (18) is the solution of

$$\left(1+(ap)^{\frac{n}{2}}\right)y=1$$

by operating with $\left[1+(ap)^{\frac{n}{2}}\right]$ on the product of the series and the function 1 we get by Leibnitz's theorem from (18)

$$\frac{t^{0}}{\lfloor 0\,a^{0}}1+\frac{n}{2}a^{n}\left[\frac{t^{n}}{\lfloor n\,a^{n}}-\frac{t^{\frac{3n}{2}}}{\left\lfloor\frac{3n}{2}a^{\frac{3n}{2}}}+\frac{t^{2n}}{\lfloor 2n\,a^{2n}}\cdots\cdots\right.\right]p1+$$

$$\frac{\left(\frac{n}{2}\right)\left(\frac{n}{2}-1\right)}{2}a^{n}\left[\frac{t^{n}}{\lfloor n\,a^{n}}-\frac{t^{\frac{5n}{2}}}{\left\lfloor\frac{5n}{2}a^{\frac{5n}{2}}}+\frac{t^{3n}}{\lfloor 3n\,a^{3n}}\cdots\cdots\right.\right]p^{2}1+\cdots \quad (20)$$

By similarly testing (19) we get

$$\frac{t^{0}}{\lfloor 0\,a^{0}}1+\left(-\frac{n}{2}\right)a\left[\frac{a^{\frac{n}{2}-1}t^{-\frac{n}{2}+1}}{\left\lfloor-\frac{n}{2}+1}-\frac{a^{n-1}t^{-n+1}}{\lfloor-n+1}\right.\right.$$

$$\left.\left.+\frac{a^{\frac{3n}{2}-1}t^{-\frac{3n}{2}+1}}{\left\lfloor-\frac{3n}{2}+1}\cdots\cdots\right.\right]p1$$

$$+\frac{\left(-\frac{n}{2}\right)\left(-\frac{n}{2}-1\right)}{2!}a^{2}\left[\frac{a^{\frac{n}{2}-2}t^{-\frac{n}{2}+2}}{\left\lfloor-\frac{n}{2}+2}\right.\right.$$

$$-\frac{a^{n-2}t^{-n+2}}{\lfloor -n+2}+\frac{a^{\frac{3n}{2}-2}t^{-\frac{3n}{2}+2}}{\lfloor -\frac{n}{2}+2}-\cdots\Bigg]p^2 1+\cdots\cdots \quad (21)$$

Since the terms in each case which are added to $\frac{t^0}{\lfloor 0\ a^0}1$ are what Heaviside calls "impulsive functions," *i.e.*, they are zero everywhere except at the point $t=0$, where they may be such that their integral is finite or infinite, it is evident that the difference between (20) and (21) can only be that due to the impulsive functions at the time $t=0$, and the solution due to such impulsive functions must be a solution of the equation

$$\left(1+(ap)^{\frac{n}{2}}\right)y=f_1(t)\,p\,1+f_2(t)\,p^2 1+\cdots\cdot\text{etc.} \quad (22)$$

or as it is generally written,

$$\left(1+(ap)^{\frac{n}{2}}\right)y=0. \quad (23)$$

If an attempt is made to find a series solution for such an equation, it is found that the series does not stop in the customary fashion at some value of n, the exponent of t, but that the series continues both ways as follows:

$$y=\cdots\cdot-\frac{t^{-\frac{n}{2}}}{\lfloor -\frac{n}{2}a^{-\frac{n}{2}}}+\frac{t^0}{\lfloor 0\ a^0}-\frac{t^{\frac{n}{2}}}{\lfloor \frac{n}{2}a^{\left(\frac{n}{2}\right)}}+\frac{t^n}{\lfloor n\ a^n}-\frac{t^{\frac{3n}{2}}}{\lfloor \frac{3n}{2}a^{\left(\frac{3n}{2}\right)}} \quad (24)$$

and more remarkable still the series may be written:

$$y=\cdots-\frac{t^{-\frac{n}{2}+r}}{\lfloor \frac{n}{2}+r\,a^{\left(-\frac{n}{2}+r\right)}}+\frac{t^r}{\lfloor r\ a^r}-\frac{t^{\frac{n}{2}+r}}{\lfloor \frac{n}{2}+r\,a^{\frac{n}{2}+r}}+\frac{t^{n+r}}{\lfloor n+r\ a^{n+r}}$$
$$-\frac{t^{\frac{3n}{2}+r}}{\lfloor \frac{3n}{2}+r\,a^{\left(\frac{3n}{2}+r\right)}}+\cdots \quad (25)$$

where r is any number between 0 and 1.

It is to be noted that the convergence on the right-hand end of these series is absolute, but the convergence on the left-hand side is asymptotic.

By splitting up these series, for instance, writing (24)

$$y = \cdots\cdots\left[-\frac{t^{-\frac{n}{2}}}{\left|-\frac{n}{2}\right| a^{-\frac{n}{2}}} - \frac{t^{\frac{n}{2}}}{\left|\frac{n}{2}\right| a^{\frac{n}{2}}} - \frac{t^{\frac{3n}{2}}}{\left|\frac{3n}{2}\right| a^{\frac{3n}{2}}} \cdots\cdots \right]$$

$$+\left[\cdots\cdots \frac{t^{-n}}{|-n|\, a^n} + \frac{t^0}{|0|\, a^0} + \frac{t^n}{|n|\, a^n} + \cdots\cdots \right] \quad (26)$$

it will be noted that both series satisfy the equation

$$(1 - a^n p^n)\, y = 0 . \quad (27)$$

Hence (26) must be capable of being written in the form

$$y = \sum_n C_n e^{\alpha_n t} \quad (28)$$

where $\alpha_1, \alpha_2 \ldots \alpha_n$ are the roots of (27) regarded as a function of p.

If the appropriate value of the constants C_n in (28) can be established to make (28) equal to (26), the relation between equations (18) and (19) can be easily obtained since

$$(19) = (26) + (18) .$$

In order to establish the values of the constants, it is not necessary to deal with the equation in the form given in (27), but we can split this up into partial fractions in a way similar to that used by Heaviside in the expansion theorem, and solve each of these equations of the first order individually. Each partial fraction gives an equation of the form

$$(p - \alpha \angle \phi)\, y = 0 \quad (29)$$

having solutions

$$y = \cdots\cdots + \frac{\alpha^{r-1} \angle (r-1)\phi\, t^{r-1}}{(r-1)!} + \frac{\alpha^r \angle r\phi\, t^r}{r!}$$

$$+ \frac{\alpha^{r+1} \angle (r+1)\phi\, t^{r+1}}{(r+1)!} + \frac{\alpha^{r+2} \angle (r+2)\phi\, t^{r+2}}{(r+2)!} + \cdots \quad (30)$$

Note that if $r = 0$ and $\phi = 0$, this equation is $e^{\alpha t}$, and if $r = 0$ and $\phi = \pi$, this equation is $e^{-\alpha t}$, keeping $\phi = 0$ and plotting

$$y = \cdots + \frac{\alpha^{r-1} t^{r-1}}{(r-1)!} + \frac{\alpha^r t^r}{r!} + \frac{\alpha^{r+1} t^{r+1}}{(r+1)!} + \cdots\cdots \quad (31)$$

for various values of $0 \leq r \leq 1$, we find that

$$y = e^{\alpha t}, \quad (32)$$

irrespective of the value of r.

Putting $\phi = \pi$ and plotting

$$y = \cdots\cdot - \frac{\alpha^{r-1} \angle (r-1)\pi\, t^{r-1}}{(r-1)!} + \frac{\alpha^r \angle r\pi\, t^{r-1}}{(r)!} - \frac{\alpha^{r+1} \angle (r+1)\pi\, t^{r+1}}{(r+1)!} + \cdots\cdots \quad (33)$$

we find that the real part of this equation is very closely equal to

$$y = \alpha^r e^{-\alpha t} \cos r\pi . \quad (34)$$

By taking various values of ϕ, it will be found that the real part of

$$y = \cdots\cdot + \frac{\alpha^{r-1} \angle (r-1)\phi\, t^{r-1}}{(r-1)!} + \frac{\alpha^r \angle r\phi\, t^r}{r!} + \frac{\alpha^{r+1} \angle (r+1)\phi\, t^{r+1}}{(r+1)!} + \cdots \quad (35)$$

is equal to

$$\frac{(\alpha^2 + \phi^2)^{\frac{r}{2}}}{2} \varepsilon^{\alpha t} \cos (\phi t + r\psi) \quad (36)$$

where $\psi = \tan^{-1} \frac{\phi}{\alpha}$.

Now these results mean that operating with p^r on the exponential and trigonometric function gives the following results:

$$p^r e^{\alpha t} = \alpha^r e^{\alpha t} \quad (37)$$

$$p^r e^{-\alpha t} = \alpha^r \cos r\pi e^{-\alpha t} \quad (38)$$

$$p^r e^{\alpha t} \cos \phi t = (\alpha^2 + \phi^2)^r \varepsilon^{\alpha t} \cos (\phi t + r\psi) \quad (39)$$

where $\psi = \tan^{-1} \frac{\phi}{\alpha}$, but when we apply the expansion theorem and take only the real part of the result, we are following these rules.

The tabulation below shows the values obtained for the following series by numerical calculation:

$$y_1 = \frac{x^{-r}}{\lfloor -r} + \frac{x^{-r+1}}{\lfloor -r+1} + \frac{x^{-r+2}}{\lfloor -r+2} + \cdots\cdots\cdots 0 \leq r \leq 1$$

$$y_2 = \frac{x^{-r}}{\lfloor -r} - \frac{x^{-r+1}}{\lfloor -r+1} + \frac{x^{-r+2}}{\lfloor -r+2} + \cdots\cdots\cdots 0 \leq r \leq 1$$

$$y_3 = \frac{-x^{-r-1}}{\lfloor -r-1} - \frac{x^{-r-2}}{\lfloor -r-2} - \frac{x^{-r-3}}{\lfloor -r-3} - \cdots\cdots 0 \leq r \leq 1$$

$$y_4 = \frac{x^{-r-1}}{\lfloor -r-1} - \frac{x^{-r-2}}{\lfloor -r-2} + \frac{x^{-r-3}}{\lfloor -r-3} - \cdots\cdots 0 \leq r \leq 1$$

when $x = 5$.

	y_1.	y_2.	y_3.	Per cent. Error (y_3).	y_4.	Per cent. Error (y_4).	(y_1-y_2).	(y_3-y_4).	$\varepsilon^{-x}\cos r\pi$.
$r=0$	ε^5	ε^{-5}	0		0		$\varepsilon^{+5}=$ 148.41	$\varepsilon^{-5}=$ .00674	.00674
$r=1/4$	148.46	−.03509	.0224	7.36	−.04088	4	148.44	.00579	.004573
$r=1/2$	141.69	−.04012	.0395	6.03	−.0404	5.9	141.65	.0003	.0000

NOTE: Per cent. error given is the maximum error possible in the asymptotic expansion for y_3 and y_4, assuming that the error is not greater than the smallest term of the series.

Thus assuming that (18) is the correct solution of the problem in question and that it does not contain a solution due to a hidden impulse since we find on a check test in (20) that all the impulsive functions $p1$, $p^2 1$, etc., are multiplied by quantities which are zero at the time $t = 0$, it is now evident that in order to obtain the correct solution using (19) we must add to it the results of applying the expansion theorem to the rationalized expression retaining only the real part obtained from the expansion theorem.

An interesting sidelight in this solution is that whereas many writers have laid stress on the fact that the solution obtained by a divergent expansion does not give the correct result, it is also a fact that applying the expansion theorem to the rationalized expression gives equally incorrect results. When fractional operators are involved the divergent expansion must be added to the real part of the result obtained from the use of the expansion

theorem. Thus it must be evident that the expansion theorem as generally stated is incomplete and only applies to integral exponents of p. If it is desired to apply it to fractional exponents, it must be modified as shown here.

We also note that it is only when the real part of the result of the application of the expansion theorem is zero, that the result is asymptotic in the true sense. In cases where terms such as e^{-at} sin ωt arise, their values would be difficult to determine for large values of t were it not for the fact that they have been already widely studied and tabulated.

At first sight the results obtained from (14) may seem inconsistent with (38). From (14)

$$\frac{p^{\frac{3}{2}}}{(p+a)}1 = p^{\frac{1}{2}}e^{-at}1$$

$$= \text{an asymptotic series given in (15).}$$

In (38)

$$p^{\frac{1}{2}}e^{-at} = a^{\frac{1}{2}}\cos\frac{\pi}{2}e^{-at}$$

$$= 0.$$

The difference is due to the fact that e^{-at} in (38) denotes the function e^{-at} from $-\infty$ to $+\infty$, whereas $e^{-at}1$ in (14) is 0 when $t < 0$ and e^{-at} when $t > 0$, since it is equal to e^{-at} multiplied by 1. The distinction between them is a very important one.

Third Method.—We shall take a specific problem to illustrate the application of the expansion theorem to a finite length of line and then take the limit as the length of the line becomes infinite.

Consider a cable with capacity and resistance C and R per unit length and an inductance L_0 between the battery, which is suddenly applied, and the cable.[3] The voltage at the beginning of the cable of length (l) is

$$V_0 = \frac{mE}{m + p^2L_0C\tan ml} \qquad (40)$$

[3] A similar problem is solved by Heaviside in "Electrical Papers," Vol. I, p. 159.

which on applying the expansion theorem becomes:

$$V_0 = E\left[1 + B + \sum_{s=1}^{\infty} \frac{2R\,\varepsilon^{-\frac{m^2 t}{CR}}}{\left(\frac{L_0 m^4 l}{CR} + \frac{R^3 l C}{L_0 m^2} - 3R\right)}\right] \tag{41}$$

where B is of the form $e^{-\alpha t}\cos \omega t$, arising from two complex roots in the denominator of (40), and where $m = \frac{S\pi}{l}$. If the length of the cable approaches infinity, the terms in the series can be summed in an integral

$$\frac{2CR^2}{L_0\pi}\int_0^{\infty} \frac{\varepsilon^{-at m^3} m^2 dm}{m^6 + b^6} \tag{42}$$

where

$$a = \frac{1}{CR}$$

$$b^6 = \frac{R^4 C^2}{L_0^2}$$

and the complex roots approach a definite limit which can be obtained by letting $l \longrightarrow \infty$ in (40) and then applying the expansion theorem. The result is

$$-\frac{4}{3} e^{-\frac{t}{2g}} \cos \frac{\sqrt{3}}{2}\frac{t}{g} \tag{43}$$

where

$$g = \sqrt[3]{\frac{L_0^2 C}{R}}.$$

A real root is encountered in thus applying the expansion theorem but is rejected since the real roots of the denominator in (40) have already been taken care of by the definite integral (42).

Thus when l is infinite

$$V_0 = E - \frac{4E}{3}\varepsilon^{-\frac{t}{2g}} \cos \frac{\sqrt{3}}{2}\frac{t}{g} + \frac{2CR^2 E}{\pi L_0}\int_0^{\infty} \frac{\varepsilon^{-a m^3 t} m^2 dm}{(m^6 + b^6)}. \tag{44}$$

The integral may be developed asymptotically by expanding $\frac{1}{m^6 + b^6}$ by the binomial theorem and integrating. Bromwich, in his "Theory of Infinite Series," shows that in this case the

error is less than the smallest term. The result is

$$V = E - \frac{4}{3}\varepsilon^{-\frac{t}{2g}} E \cos\frac{\sqrt{3}}{2}\frac{t}{g} + \frac{E}{2\sqrt{\pi}}\left(\frac{g}{t}\right)^{\frac{3}{2}}$$

$$\left[1 - 3\cdot5\cdot7\cdot\left(\frac{g}{2t}\right)^3 + 3\cdot5\cdot7\cdot9\cdot11\cdot13\left(\frac{g}{2t}\right)^6 + \cdots\right] \tag{45}$$

which corresponds with Heaviside's result ("Electromagnetic Theory," p. 44).

The convergent solution given in "Electromagnetic Theory" (p. 43) is more difficult to obtain from (44). It may, however, be obtained by splitting the integral into three integrals by partial fractions.

$$\int_0^\infty \frac{e^{-m^3at}m^2dm}{m^6+b^6} = -\frac{1}{3b^2}\int_0^\infty \frac{e^{-m^3at}dm}{m^2+b^2} - \frac{1}{3b^2\angle 120}\times$$

$$\int_0^\infty \frac{e^{-m^3at}dm}{m^2+b^2\angle 120} - \frac{1}{3b^2\angle -120}\int_0^\infty \frac{e^{-m^3at}dm}{m^2+b^2\angle -120}. \tag{46}$$

It can be shown that

$$I = \int_0^\infty \frac{e^{-m^3at}dm}{m^2+b^2\angle\phi} \tag{47}$$

is a solution of the differential equation

$$\frac{dI}{dt} - b^2a\angle\phi\, I = -\frac{\pi\sqrt{a}}{2}\frac{t^{-\frac{1}{2}}}{\left|-\frac{1}{2}\right.}. \tag{48}$$

Hence $I = Ce^{b^2a\angle\phi t}$ + a series in ascending powers of $t^{\frac{1}{2}}$, $t^{\frac{3}{2}}$, etc.

The constants C_1, C_2 and C_3 may be determined for the three integrals in (46) from a consideration of the value of the integrals at $t = 0$, and on adding together the results, and substituting series for the exponentials, the convergent series given by Heaviside ("Electromagnetic Theory," p. 43) is obtained.

NOTE ADDED JANUARY, 1928.

After this paper had been transmitted to The Franklin Institute for publication, a paper by H. W. March on the Heaviside Operational Calculus appeared in the *Transactions of the American Mathematical Society*, May–June, 1927, in which the validity of the asymptotic expansion was examined. Professor March found that if, when $1/H(p)$ (which corresponds to $\phi(p)1/x(p)$ in our notation in equation (1)) was expanded in rising powers of p, the expansion contained only powers of p and $p^{\frac{1}{2}}$, the result obtained on proceeding in the usual manner is correct if $1/H(p)$, when rationalized, does not contain any zeros in the denominator except those along the real negative axis. This agrees with the result obtained here since, for the added terms, on evaluating by the expansion theorem, we get terms of the type $p^{\frac{1}{2}}e^{-\alpha t}$ (α being real and positive), which gives imaginary terms and should, therefore, be rejected according to the rule.

It should be carefully noted that the result given by Professor March is only correct when $1/H(p)$ expanded in rising powers of p contains only powers of p and $p^{\frac{1}{2}}$. It would not be correct to assume it to be true if terms such as $p^{\frac{1}{3}}$ entered since $p^{\frac{1}{3}}e^{-\alpha t}$ is not wholly imaginary and would, therefore, give an additional term on the application of the expansion theorem, in spite of the fact that a term such as this would not prevent the path of the contour integral to be deformed into that given by Professor March in Fig. 1.

It should not be very difficult to modify Professor March's work to supply an additional verification of the work given here. For instance, if in the last equation of his paper the path of integration be deformed to his path of Fig. 1 plus contours around the singularities at $p = \pm iw$, the integrals around these latter points should give the results of applying the expansion theorem to $1/H(p)$ when rationalized.

Sugar and Alcohol from Cellulose. (The British Empire Producers' Organization.)—A report has been received by the Power Alcohol Section of the organization of the first tests carried out in a factory in Germany on a commercial scale for using sawdust, straw, sisal waste and bagasse as raw materials for the production of grape sugar and ethyl alcohol.

The process consists of the saturation by hydrochloric gas, in the presence of catalysts, of the raw materials, and in a period of under one hour the whole of the cellulose content is converted into glucose. This glucose is then treated for the removal of the acid, and can be either sold as cattle food, or refined as pure white glucose for human consumption, or it can be fermented into alcohol for fuel, industrial and potable purposes. As much as 60 per cent. of the weight of the dried sawdust has been obtained in pure sugar, and in the case of straws and other materials higher percentages are obtained.

The development of such a process must have a far-reaching effect in the Dominions and Colonies where large supplies of raw material of the kind mentioned are now being wasted, and also in those countries where abundant supplies of grasses and bamboos are available, as these materials are equally suitable for conversion into alcohol.

Various European governments are investigating the process and the Australian Government has sent a representative. It seems probable that this process in the near future will provide countries with an alternate motor fuel supply to that of petrol.

Crystalline Carnotite.—FRANK L. HESS and WILLIAM F. FOSHAG (*Proc. U. S. National Museum*, 1927, **72**, Article 12, 1–6) describe the occurrence of the mineral carnotite in the crystalline form at Bridger Jack, Utah. The crystals are clear, yellow plates, and are unusually pure, being free from barium, copper, phosphorus, arsenic, and molybdenum. An appreciable amount of lime and a small amount of sodium are present; and the water content is much lower than usually found in carnotite. The results obtained on analysis agree closely with the theoretic formula, $K_2O.2UO_3.V_2O_5.\frac{2}{3}H_2O$. The radio-activity of the crystals is approximately 68 per cent. of that when radium is in equilibrium with uranium; therefore the mineral is about 6,800 000 years old. J. S. H.

Preparation of Pyrrole.—F. F. BLICKE and J. L. POWERS, of the University of Michigan (*Ind. and Eng. Chem.*, 1927, 19, 1334–1335), have studied the preparation of pyrrole from ammonium mucate and glycerol. As much as 5.5 pounds of ammonium mucate was mixed with its own weight of glycerol, and the mixture was heated in a retort. Crude pyrrole, separated from the distillate, was purified by drying with solid sodium hydroxide, and was redistilled. The yield of purified pyrrole ranged between 41 per cent. and 51 per cent. of the calculated amount. J. S. H.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

PERCEPTION OF SLIGHT COLOR DIFFERENCES.

COTTONSEED and other vegetable oils are graded by color, and the color is an important item in determining the price which the oil commands on the market. The Bureau of Standards is coöperating with the American Oil Chemists' Society in establishing color standards for this purpose.

However, the reliability of the color grading is not assured merely by providing correct standards. The color sense of the person who does the color grading must be considered, especially his ability to perceive small differences in hue for yellows.

At the request of the American Oil Chemists' Society, Mr. Irwin C. Priest of the bureau has conducted tests of the color sense of about thirty of the society's members; and the results were published in the January number of its official organ, *Oil and Fat Industries*.

This test was especially designed to measure the observer's ability to perceive small differences at the color which is standard for prime yellow oil. The method of test was that of "right and wrong answers," the observer reporting color differences as they appeared to him, while the conductor of the experiment kept a tally of correct and incorrect answers. A score of 9 or 10 correct answers in 10 trials indicates that the observer is able to detect the difference with practical certainty.

The results of these tests, which are regarded as preliminary rather than final, indicate that many of the chemists (perhaps one-third or even two-thirds) are unable to discern *with certainty* the smallest differences which are considered in color grading the oil in present trade practice. It should be noted, however, that these differences are so small that only exceptional observers can be expected to be certain about them. One or two were found to be quite incompetent to do color grading, being very uncertain about differences which are unmistakable to competent normal observers. At least four fell below what might be reasonably accepted as a normal ability to perceive hue differences.

Incidentally, these tests have shown that the normal observer's

* Communicated by the Director.

sensibility to difference in wave-length is much greater than has been believed heretofore. Good observers can detect with certainty a difference of wave-length as small as 1/10,000,000 of a millimetre for yellow light. This is of the order of 1/5 or 1/10 of what has been given as the "least perceptible difference" by previous authorities. This aspect of these data has been discussed in a paper communicated to the Optical Society of America at its meeting in Schenectady, October, 1927, and will appear in abstract in the February number of the *Journal of the Optical Society*.

REPORT OF COMMISSION ON RADIO WAVE PROPAGATION.

THE large amount of work being done in what may be called the physics of radio transmission is described in the report of the Commission on Radio Wave Propagation of the International Union of Scientific Radio Telegraphy presented at the recent meeting in Washington by the chairman of the commission, Dr. L. W. Austin, of the Bureau of Standards. Among the facts of general interest mentioned in this report are the following: It is found that in England in summer the reflection from the Kennelly-Heaviside layer is so strong even in the daytime that the signals from a French transatlantic station near Paris alternately increase and decrease in strength as the distance to the receiving station is increased. This seems to be the result of interference by ground and reflected waves. Thus, the signals at Aberdeen, 621 miles away, are about three times as strong as at Manchester, 373 miles distant. It is also found that the variability from day to day in long-wave daylight signals (above 10,000 m.) is generally nearly independent of the distance, beyond 155 miles. The French committee reported that in tropical Africa, contrary to the experiments in most parts of the world, they find no skip distance in the ultra-high-frequency waves, that is, no range of distance over which no signals are heard, while they are strong at both shorter and longer distances. The English committee finds in regard to the apparent night direction variations of sending stations that they are independent of wave-length above 300 m. and that the errors in apparent direction reach a maximum at about 150 miles over land and at about 450 miles over sea and that they are slight for distances beyond 3000 miles. In America, more evidence is constantly being found

for a relationship between solar activity (sun-spots) and signal strength.

SPECIFICATIONS FOR AUTOMOTIVE AND RADIO STORAGE BATTERIES.

THE proposed master specifications for automotive and radio storage batteries which were prepared by a technical committee of the Federal Specifications Board were discussed at a conference of storage battery manufacturers held at the Bureau of Standards on December 19th. The automotive specifications are essentially a revision of similar specifications prepared six years ago, which have been subsequently used by the Motor Transport Division of the War Department. The principles were discussed by the conference, but as the time was insufficient to reach agreement on all of the technical details a committee was provided for to continue the work. This committee, which has not yet been appointed, is to consist of representatives from the Society of Automotive Engineers, the National Electrical Manufacturers' Association, the Bureau of Standards and two battery manufacturers at large. It is expected that this committee will be appointed and begin its work early in the present year.

The proposed specifications were sent to a large number of battery manufacturers and organizations interested in the preparation of these specifications. Those in attendance included representatives of the National Electrical Manufacturers' Association, the Electric Storage Battery Company, the Philadelphia Storage Battery Company, Carlile and Doughty, Prestolite Storage Battery Corporation, U. S. L. Battery Corporation, Willard Storage Battery Company, and Westinghouse Union Battery Company. In addition to these manufacturers, representatives of Government departments were present from the Bureau of Standards, the National Committee on Wood Utilization, the Engineering Section of the Motor Transport Division of the Quartermaster Corps, and the Signal Corps of the War Department, Bureau of Engineering, Navy Department, and the Department of Agriculture.

THERMAL EXPANSION OF FELDSPAR.

Technical News Bulletins No. 117 (Jan., 1927), *No. 121* (May, 1927), and *No. 123* (July, 1927) summarized the work to date in the investigation of the effect of feldspar in white ware

bodies. This report is a summary of the study of the thermal expansion, by the interferometer method, of partially and completely fused feldspars fired to cones 4, 8, 10, 12, 13, and 14. There are nineteen feldspars included in the investigation, ranging in composition from No. 1, which is almost pure albite, a high Na_2O content feldspar, to No. 19, which is a practically pure specimen of orthoclase, a high K_2O content feldspar.

The data obtained show:

(1) The expansion of all the feldspars fired to the above temperatures proceeds quite regularly until a temperature of 575° C. or 1067° F. is reached, when the rate of expansion increases decidedly because of a property characteristic of quartz which at this temperature changes suddenly from the α form to β form of crystallization. This expansion of flint is not to be confused with the regular heat expansion of the feldspar, but is an additional change which is peculiar to the flint. Since this extra expansion is not part of the expansion of the flint-free spar, the true per cent. linear expansion at 560° C. is reported.

(2) The thermal expansion of a feldspar fired below cone 8 is low, becomes normal at cone 8, and drops again when the firing temperature rises above cone 8. Obviously this will depend upon the amount of flint in the feldspar. The low expansion of the underfired feldspar results from the fact that there is so much pore space in proportion to the solid mass, and that the flint is still present in the unaltered state. The low expansion of the overfired feldspar is due to the fact that the flint has been dissolved by the fused feldspar. Silica has a very high expansion as long as it remains quartz, but has a low expansion when it has been dissolved to a glass by feldspar.

(3) The highest expansions noted for feldspars fired to cone 8 are for spars 6 and 7 (relatively low K_2O content feldspars), and are the result of their high silica content. The lowest expansion noted for feldspars fired to cone 8 is for spar No. 1, which is an almost pure albite (Na_2O feldspar). For cone 10 the highest expansion is seen with spars 6 and 7, due again to their high silica content, while the lowest expansion is found with spar No. 19, a high K_2O content spar.

Therefore, it seems logical to conclude that the silica content has more influence upon the expansion of partially and completely

fused feldspars than the Na_2O or K_2O content, or the fineness of the grind.

The following table shows the per cent. linear expansion of the partially and completely fused feldspars at 560° C., together with their softening points and the percentages of free silica content.

Spar No.	Cone.						Softening Point. Cone.	Per Cent. Free SiO_2.
	4	8	10	12	13	14		
1	.284	.402	.406				4	2.8
2	.328	.487	.468				5	21.8
3	.286	.438	.437				4	11.4
4		.484	.462		.418		6	20.4
5		.482	.460		.394		5	21.2
6		.522	.593		.464		7 HD	20.0
7		.542	.594		.476		7	25.1
8		.475	.446		.444		6 HD	11.3
9		.489	.480		.483		7	17.6
10		.460	.450		.443		7 HD	10.6
11		.476	.466		.452		7 HD	12.4
12		.469	.470		.437		7	12.5
13		.450	.448	.434		.409	8	12.0
14		.438	.466	.470		.430	8 HD	12.6
15		.418	.452	.438		.422	8	8.5
16			.458	.473		.420	8	12.7
17			.387	.404		.401	10 HD	6.9
18			.427	.413		.406	8	1.9
19			.396	.421		.450	9	2.2

TESTS OF LARGE CONCRETE CYLINDERS.

DURING the month of December the bureau tested a large group of concrete cylinders. The cylinders were made during the construction of the Santeetlah Dam of the Tallahassee Power Company, shipped, protected by moist cinders and burlap, by flat car to the bureau and tested at the age of approximately three months. They were all in the proportion of height equal to twice the diameter, and had been accurately made to dimension. There were eight sizes of specimens, 2, 3, 6, 8, 12, 18, 24, and 36 inches in diameter. The largest cylinders weighed approximately 6300 pounds, and were considerably larger than any heretofore tested.

The ends of the 2-inch and 3-inch cylinders were ground to a plane surface before testing. The 6-, 8-, and 12-inch cylinders were capped with plaster-of-Paris previous to being placed in the

testing machine. The larger cylinders were capped in the testing machine. All aggregate was obtained from crushing the natural rock. The larger pieces of the aggregate were bounded in general by two flat surfaces indicative of the lamellar nature of the rock. The pieces were not thin, the proportion of length to thickness being in the nature of one to six. The maximum size of the aggregate varied, running to a maximum of 10-inch material in some of the larger cylinders. The fine aggregate was obtained from the same rock, practically all passing the ⅜-inch sieve and having an approximate fineness modulus of 3.5.

Examination of the aggregate showed two types, one a laminated and fibrous rock, evidently a schist, containing biotite, muscovite, pyrite, a little quartz and one unidentified mineral, possibly pyrophyllite, the other a gneiss composed of biotite, muscovite, quartz, plagioclase, feldspar and one or two unidentified minerals present in small amounts.

One group of cylinders, including specimens of every size, was made in the proportion of one part cement to 2.7 parts of aggregate, all aggregate having been smaller than the ⅜-inch sieve. In this group the 36-inch cylinders developed an average compressive strength of 2550 lbs./in.^{2}, the 12-, 18-, and 24-inch specimens approximately 3000 pounds, the 6- and 8-inch specimens 4100 pounds, and the 2- and 3-inch specimens approximately 5100 lbs./in.^{2}.

In the other groups of cylinders the 36-inch cylinders contained aggregate of maximum size varying from 2½-inch to 10-inch, proportions being approximately 1 : 3 : 3, 1 : 3 : 4 and 1 : 3 : 4.6. Before filling the 8-inch molds, all aggregate above 2½-inch was removed from the concrete, for the 6-inch molds all above 1½-inch and for the 2- and 3-inch molds all above ⅜-inch. The strength of the 36-inch diameter cylinders varied from 1500 to 3100 lbs./in.^{2}, compared with the minimum and maximum average strengths of 2260 and 4400 for the 8-inch, and 3130 and 4700 for the 6-inch cylinders. There was a general tendency for the smaller specimens to give higher strengths.

Stress strain readings were taken on the 18-inch and 36-inch diameter cylinders, readings being taken without stopping the application of load. The readings were continued until maximum load was reached. The ultimate strains varied from .0015 to

.0032 in. per inch, and the initial modulus of elasticity varied from 2,200,000 to 3,600,000 lbs./in.^{2}. In all cases the average modulus for the 36-inch cylinders was higher than for the 18-inch cylinders.

POISSON'S RATIO AND THE MODULUS OF ELASTICITY OF SAND-LIME BRICK.

SOME recent work on sand-lime brick at the Bureau of Standards has consisted in testing this product for stress-strain relationships. The loads were applied by a 20,000-pound testing machine, while the strains were determined by the use of Tuckerman optical strain gauges. The latter gave most excellent results, and furnished a very accurate picture of what occurred when the loading was increased or diminished. Incidentally, the results speak well for the uniformity of these bricks.

Twelve bricks were tested. Four were tested in tension, four in compression on end, and four in compression edgewise. With the bricks tested on edge the secant modulus of elasticity varied from an average value of about 1,700,000 lbs./in.^{2} at no load to about 1,600,000 at a stress of 1000 lbs./in.^{2}. For a second loading the modulus of elasticity was nearly constant throughout the loading and its average value was about 1,600,000 lbs./in.^{2}. The modulus of elasticity in compression was about equal to the modulus in tension.

For the modulus of elasticity determinations, readings of strain were obtained on two gauges attached at the centre of the length on opposite sides of the brick. It was found that with a slightly eccentric loading in compression the readings for the two gauges were unequal, but the averages were approximately the same as for concentric loading.

Both the longitudinal strains (in the direction of the loading) and the transverse strains (at right angles with the direction of the loading) were determined on one brick. From these strains the value of Poisson's ratio (the ratio of the transverse to the longitudinal strain) was found to be one-seventh throughout the range of the loading.

Three bricks were tested for changes in strain while being loaded transversely, that is in bending. The supporting knife edges were seven inches apart and the load was applied on top

at the centre of the span. A notch was cut in the upper knife edge so that it could straddle the gauge. To insure pressure directly under the gauge, as well as elsewhere, a steel strip extended across the brick under the gauge and under the knife edge so that the load would be distributed properly. There was close agreement between the compression of the upper side and the elongation of the lower side—these relations holding also when the brick was turned over and tested again. This would indicate that the neutral axis lay in a plane half-way between the upper and lower sides.

NOTES FROM LIGHTING RESEARCH LABORATORY, NATIONAL LAMP WORKS OF THE GENERAL ELECTRIC COMPANY.*

FOUR FUNDAMENTAL FACTORS IN VISION.

By P. W. Cobb and F. K. Moss.

THE problem of lighting for visual work is always a specific one and vision is necessarily the final criterion of the merits of the lighting. There are at least four fundamental variables involved in vision and any one of these may be of critical importance in the particular visual situation. Clear seeing results only when all variables have been given due consideration with reference not only to the lighting, but with reference to vision as well. The fundamental variables in a visual object are:

(1) Size of the critical detail of object;
(2) Contrast between object and its background;
(3) Brightness of the object;
(4) Time allowed for seeing the object.

An experimental analysis was made of the quantitative interrelation of these four characteristic variables of the visual object at the border of visibility. The table summarizes the results of the experiment.

EXPLANATION OF TABLE.

The first column of the table gives the smallest dimension of the test-object, in minutes of angle at subject's eye. The columns *a, a, a* give the values of contrast required (per cent.) for the threshold at 100, 20, and 1 ml., respectively. In columns *b, b, b,* respectively, are given the probable errors of these averages. The time series (columns *c, d, e; c, d, e*) were run separately. Of these, the value 0.170 second should check with the corresponding value in column *a*. Each value in the table is the geometric mean result from nine subjects, each representing an average of five series, taken by the method of serial groups. Thus each value in

* Communicated by the Director.

the table represents 45 series of observations, or perhaps 2000 separate observations.

Size of T.O.	Per Cent. Contrast.											
	Brightness = 100 Ml.					Brightness = 20 Ml.		Brightness = 1 Ml.				
	Time 0.170.	E Rel.	Time.			Time 0.170.	E Rel.	Time 0.170.	E Rel.	Time.		
			0.075.	.170.	.300.					.075	.170.	.300.
16.02	1.14	.008	1.27	1.14	1.04	1.57	.014	1.82	.009	2.73	2.46	2.22
11.31						1.80	.013	2.29	.013			
7.98	1.50	.010				2.16	.012	3.07	.014			
5.67						2.71	.014	4.30	.014			
3.95	2.43	.014				3.71	.012	7.27	.017			
3.20						4.92	.013	10.8	.016			
2.41	4.67	.018	5.35	4.56	4.08	6.87	.016	17.1	.021	22.3	17.9	15.6
1.93						9.96	.015	27.8	.018			
1.63	8.13	.013				14.1	.015	40.4	.014			
1.35						20.9	.017	60.1	.016			
1.17	15.2	.016				30.1	.017			95.7	82.7	67.3
0.986						48.5	.021					
0.797	44.7	.013	54.2	43.7	37.4							
	a	*b*	*c*	*d*	*e*	*a*	*b*	*a*	*b*	*c*	*d*	*e*

A detailed report of this investigation will appear shortly in the *Transactions of the Illuminating Engineering Society*. In addition, the above data have been graphically represented in a three-dimensional cardboard model.

NOTES FROM THE RESEARCH LABORATORY, EASTMAN KODAK COMPANY.*

THE LUBRICATION OF MOTION PICTURE FILM.[1]

By J. I. Crabtree and C. E. Ives.

To facilitate its passage through the projector, it is necessary to apply some sort of lubricant to the surface of motion picture film. If this is not done an accumulation of hardened gelatin forms on the projector gate and the friction which results often entirely arrests the progress of the film.

Present lubricating practice consists in applying a thin line of wax along each edge of the film. This is satisfactory but there is a tendency to apply too much wax, which encroaches on the picture areas and causes spots and blotchiness on the screen. Also the presence of too much wax in the gate is apt to cement the film to the aperture plate if the projector is threaded when warm and then allowed to cool, so that on starting the projector the film remains stationary in the gate and is apt to catch fire.

The above objections have been overcome by applying a solution of wax dissolved in carbon tetrachloride to the entire surface of the film and then buffing this. The result is to impart a high polish to the film surface analogous to that on polished footwear. This treatment insures sufficient lubrication, and film so treated is impervious to the effect of oil, so that the trouble from patchiness and blotches on the screen caused by oils is eliminated.

A COMPACT MOTION PICTURE DENSITOMETER.[2]

By J. G. Capstaff and R. A. Purdy.

A PORTABLE densitometer was designed to measure the small densities occurring in motion picture images. An automobile headlight lamp is used both to furnish the comparison and to illuminate the density to be measured. The intensity of the density

* Communicated by the Director.

[1] Communication No. 330 from the Kodak Research Laboratories and published in *Trans. Soc. Mot. Pict. Eng.*, 11, No. 31, 522, 1928.

[2] Communication No. 331 from the Kodak Research Laboratories and published in *Trans. Soc. Mot. Pict. Eng.*, 11, No. 31, 606, 1928.

beam is reduced by a known amount by a photographic wedge. The comparison beam is a constant brightness. By an arrangement of mirrors the comparison field is constructed to give a photometric field which is viewed with a low-powered eye-piece.

The instrument is capable of measuring densities from 0 to 3. The scale reads directly in densities.

THE PHOTOGRAPHIC REFLECTING POWER OF COLORED OBJECTS.[3]

By L. A. Jones.

SOME quantitative data relative to the photographic reflection factors of colored objects are given. As an introduction of the subject the theoretical phases of the question are considered. The factors upon which visual and photographic reflection factors depend are discussed. It is shown that photographic reflection factor depends upon the spectral distribution of energy in the illuminating radiation, the visibility function of the human eye, and the spectral absorption of the colored object in question. Likewise it is shown that photographic reflection factor depends upon the spectral quality of the illuminant, the spectral absorption of the colored object, the spectral sensitivity of the photographic material, and the selective absorption of the lens used in the camera. The practical photographic photometric method of measuring reflection factors is discussed, and photographic reflection factors for twenty-five color panels are given, the measurements being made on photographic materials of different color sensitivity and with light sources of different types.

FACTORS AFFECTING THE CONTRAST OF A LENS IMAGE IN THE MOTION PICTURE CAMERA.[4]

By C. Tuttle and H. E. White.

AN IMAGE which duplicates the contrast of the object is desirable in photography. Such a condition makes for a clear, sparkling picture, but if the lens image contrast differs greatly

[3] Communication No. 327 from the Kodak Research Laboratories and published in *Trans. Soc. Mot. Pict. Eng.*, 11, No. 31, 564, 1928.

[4] Communication No. 329 from the Kodak Research Laboratories and published in *Trans. Soc. Mot. Pict. Eng.*, 11, No. 31, 591, 1928.

from that of the object, the quality of the photographic reproduction will suffer.

In motion picture photography a number of causes such as lens flare, camera interior reflections, diffusion, and light leaks may result in lowered image contrast. The seriousness of these various factors and the possible remedies for some of them are discussed. Especial attention is given to the practical value of lens shades in preventing the entrance of extraneous light.

Biophysics of the Common Fowl.—H. H. MITCHELL and W. T. HAINES, of the Illinois Agricultural Experiment Station (*Jour. Agric. Res.*, 1927, **34**, 549–557), have determined that the critical temperature of the chicken has an average value of 62° F. This temperature is defined as the environmental temperature at and below which the heat production of the fasting resting animal will increase in order to prevent a lowering of the body temperature. The value for the chicken is based on thirty-six experiments with twelve Rhode Island Red hens, winter feathered birds, in an atmosphere of low humidity, and in an air current of approximately 3 litres per minute.

MITCHELL and HAINES (*Jour. Agric. Res.*, 1927, **34**, 927–943) also determined the basal heat production or basal metabolism of twenty-eight non-laying hens, and found it to be 54.9 calories per day per kilogram of body-weight, and 703 calories per day per square metre of body surface. For nineteen mature cocks, the average values found were 55.7 and 806 calories, respectively. J. S. H.

Fabrics and Sunburn.—KATHERINE HESS, J. O. HAMILTON, and MARGARET JUSTIN, of the Kansas Agricultural Experiment Station (*Jour. Agric. Res.*, 1927, **35**, 251–259), find that the protection from sunburn which is afforded the skin by fabrics depends primarily on the amount of interspace due to weave. However, the vegetable fibres, cotton and linen, transmit some of the rays which burn and tan, while the animal fibres, wool and silk, absorb a larger portion of these rays. Therefore, silk and wool offer a higher coefficient of protection against the actinic rays than do cotton and linen. J. S. H.

BEFORE Moseley had promulgated the idea of atomic numbers and had shown that there cannot be more than ninety-two elements unless an element heavier than uranium be found, it was easy to account for an unidentified spectral line in sun, star or nebula by attributing to some otherwise unknown element, such as nebulium. In *Nature*, Oct. 22, 1927, A. FOWLER, Imperial College of Science, remarks: "It is, of course, no longer permissible to suppose the existence of hypothetical elements to account for the long-standing mysteries of nebular spectra, and we must accordingly regard the nebular lines as being produced by known elements under conditions of excitation which have not yet been imitated in the laboratory." G. F. S.

Occurrence of Germanium.—JACOB PAPISH, F. M. BREWER, and DONALD A. HOLT, of Cornell University (*Jour. Am. Chem. Soc.*, 1927, **49**, 3028–3033), report the occurrence of germanium in traces in certain tin ores, and in appreciable traces (0.013 to 0.033 per cent.) in certain varieties of the mineral enargite, a cuprous thioarsenate which is an ore of copper. J. S. H.

NOTES FROM THE U. S. BUREAU OF CHEMISTRY AND SOILS.*

STUDIES ON GOSSYPOL. I. THE PREPARATION, PURIFICATION, AND SOME OF THE PROPERTIES OF GOSSYPOL, THE TOXIC PRINCIPLE OF COTTONSEED.[1]

By E. P. Clark.

[ABSTRACT.]

GOSSYPOL, the toxic principle of cottonseed, was prepared in a state of analytical purity and certain properties of this purified material were determined. Its molecular formula was ascertained to be $C_{30}H_{30}O_8$. Analytical data were obtained upon several derivatives of gossypol. These included the so-called acetate, anhydrogossypol, the dianilide, the dioxime, and the hexaacetyl derivative. It was found that the dianilide, which is important because of its use in the quantitative determination of gossypol, was a condensation product formed by 1 mol of gossypol condensing with 2 mols of aniline, with the elimination of 2 mols of water. Of the eight oxygen atoms in gossypol, two were carbonyl groups, whereas the remaining six were hydroxyl groups. Two of these hydroxyl groups behaved differently from the remaining four in that they were much more acidic and required drastic treatment for the hydrolysis of their acetyl derivative. A short report concerning some interesting physiological effects of gossypol upon rats is given.

PRODUCTION OF GLUCONIC ACID BY THE PENICILLIUM LUTEUM-PURPUROGENUM GROUP I.[2]

By Orville E. May, Horace T. Herrick, Charles Thom and Margaret B. Church.

[ABSTRACT.]

A SURVEY was made of the action of 172 different strains of fungi on glucose solutions of varying strengths with the object of ascertaining whether acids other than citric or oxalic were

* Communicated by the Chief of the Bureau.

[1] Published in the *Jour. Biol. Chem.*, **75**, No. 3, December, 1927, pp. 725-739.

[2] Published in the *Jour. Biol. Chem.*, **75**, No. 2, November, 1927, pp. 417-422.

produced. The fungi included the genera *Aspergillus, Penicillium, Monilia,* and *Mucor*. The only fungi other than the *Aspergilli* which produced acid in large quantities were certain strains of *Penicillia*. Gluconic and citric acids were isolated from the culture solutions of *Penicillium citrinum* and *Penicillium divaricatum*. In fourteen days certain strains of the *Penicillium luteum-purpurogenum* group produced gluconic acid alone, in yields as high as 60 per cent. of the theoretical quantity. The acid was identified by means of the calcium and barium salts; the specific optical rotation of these salts was determined and reported as 9.8° and 9.0°, respectively.

THE FRANKLIN INSTITUTE.

(Proceedings of the Stated Meeting Held Wednesday, January 18, 1928.)

THE annual meeting of The Franklin Institute was called to order at eight-twenty P.M. by Vice-president Tutwiler, who presided in the absence of the President, Dr. Wm. C. L. Eglin, who was away because of illness.

The Chairman called upon the Secretary for the minutes of the last meeting. The Secretary reported that these minutes had been printed in full in the January number of the JOURNAL of the Institute and moved that they be approved as printed. This motion was unanimously adopted. The minutes were declared approved.

The Chairman next called upon the Secretary to read the results of the annual election. The Secretary read the report submitted by the Tellers—Doctors Leffmann and Dike and Mr. Adams—which showed that the following gentlemen had been unanimously elected to the positions indicated:

Total number of votes cast, 373.
President: (to serve 1 year), Wm. C. L. Eglin.
Vice-president: (to serve 3 years), Henry Howson.
Treasurer: (to serve 1 year), Benjamin Franklin.
Managers: (to serve 3 years), Francis T. Chambers.
Morris L. Clothier.
Nathan Hayward.
Robert W. Lesley.
Marshall S. Morgan.
E. H. Sanborn.
S. T. Wagner.
J. T. Wallis.

The Chairman then declared the gentlemen nominated to be elected to the respective offices.

The Secretary reported that because of illness, the President was unable to present his annual report at this time. It will be presented at a later meeting.

The Secretary then made a statement concerning the Christmas Week Lectures, described their origin and purpose, and made announcement concerning the prizes which had been offered and won. He requested Dr. E. E. Wildman, Director, Division of Science, Board of Public Education, to present the prizes. Doctor Wildman, in happy terms, made the presentations.

The first prize of fifty dollars was awarded to Ralph F. Scholl, Northeast High School. Second prize—$25—David MacAdam, Upper Darby High School. Third prize—$10—Biddle Walker, Upper Darby High School. Honorable mention: James C. Hargreaves, West Philadelphia High School; Walter Levin, Northeast High School.

The Secretary stated that the money for the prizes had been donated by the President and one of the Vice-presidents of the Institute.

The Committee of Judges who passed upon the note-books was composed of Prof. Walter T. Taggart, Department of Chemistry, University of Pennsylvania; Prof. H. Jermain Creighton, Department of Chemistry, Swarthmore College, and Dr. Howard McClenahan, Secretary of the Institute.

There being no further business, the Chairman presented as the lecturer of the evening, the Honorable Edward P. Warner, Assistant Secretary of the Navy for Aeronautics, who spoke delightfully upon the subject, "The Engineering of Naval and Civil Aircraft."

The meeting adjourned at nine-thirty, with a rising vote of thanks and of hearty appreciation of Secretary Warner's stimulating talk.

HOWARD MCCLENAHAN,
Secretary.

COMMITTEE ON SCIENCE AND THE ARTS.

(Abstract of Proceedings of Stated Meeting Held Wednesday, January 4, 1928.)

HALL OF THE COMMITTEE,
PHILADELPHIA, January 4, 1928.

MR. M. M. PRICE, *in the Chair.*

The following reports were presented for final action:

The Franklin Medal, Dr. James Barnes, Chairman.

No. 2886: To Dr. Charles F. Brush, Electrical Engineer, of Cleveland, Ohio, "in recognition of his invention and development of the first successful arc light system for illumination and of the first practical storage battery."

No. 2887: To Dr. Walther Nernst, Professor of Physical Chemistry at the University of Berlin, and Director of Technical Physics at the Reichsanstalt, Charlottenburg, Germany, "in recognition of his numerous and valuable contributions in physical and theoretical chemistry and particularly for his applications of the exact methods of thermodynamics to electro- and thermo-chemistry."

The following report was presented for first reading:

No. 2882 Wide-angle, High-speed Lens, Dr. Winthrop R. Wright, Chairman.

GEO. A. HOADLEY,
Secretary to Committee.

MEMBERSHIP NOTES.

ELECTIONS TO MEMBERSHIP.

(Stated Meeting, Board of Managers, January 11, 1928.)

LIFE-RESIDENT.

DR. AUGUSTUS ADOLPH ESHNER, Physician, 1019 Spruce Street, Philadelphia, Penna.

RESIDENT.

MR. WILSON NORRIS DURHAM, Radio Engineering, President, Durham and Company, Inc., 1936 Market Street, Philadelphia, Penna.

DR. ELLICE MCDONALD, Physician, Physicians' Building, Twentieth and Chestnut Streets, Philadelphia, Penna.

DR. WILLIAM ROGERS, JR., Teacher, Temple University. For mailing: 6727 North Broad Street, Philadelphia, Penna.

NON-RESIDENT.

MR. MORRIS KNOWLES, Consulting Engineer, President, Morris Knowles, Inc., 507 Westinghouse Building, Pittsburgh, Penna.

MR. LISS C. PETERSON, Engineer, American Telephone and Telegraph Company, Room 1611, 195 Broadway, New York City, N. Y.

CHANGES OF ADDRESS.

DR. HERBERT A. CLARK, in care Taylor Instrument Companies, Ames Street, corner West Avenue, Rochester, N. Y.

MR. J. S. DUNCAN, 5555 Everett Avenue, Hyde Park Station, Chicago, Ill.

MR. J. HALMER HAYNER, Mayfair House, Germantown, Philadelphia, Penna.

MR. THOMAS D. J. LEECH, The University of Sydney, New South Wales, Australia.

MR. W. E. RICHARDSON, 225 South Fortieth Street, Philadelphia, Penna.

MR. RAYMOND W. ROSS, 4730 Bingham Street, Apartment A, Philadelphia, Penna.

DR. C. C. THOMAS, 165 Puente Drive, Pasadena, Calif.

LIBRARY NOTES.

RECENT ADDITIONS.

American Annual of Photography, 1928. Volume 42. 1927.

American Men of Science. Fourth edition. 1927.

BALY, E. C. C.—Spectroscopy. Third edition. Volume 3. 1927.

Chemical Abstracts.—Decennial Index 1917–1926, Volumes 11–20. (Author index.) Two volumes. 1927.

GEIGER, H., and KARL SCHEEL, Editors.—Handbuch der Physik. Bände 5, 8, 16. 1927.

Geological Society Quarterly Journal. Index to the first fifty volumes. 1897.

KLEMGARD, E. N.—Lubricating Greases. 1927.

National Research Council.—Annual Survey of American Chemistry. Volumes I and II. 1926–1927.

Siemens-Konzern.—Wissenschaftliche Veröffentlichungen. VI Band, erstes Heft. 1927.

TUTTON, A. E. H.—The Natural History of Ice and Snow: Illustrated from the Alps. 1927.

Worthington Pump and Machinery Corporation.—Pump Handbook. 1927.

Zeitschrift für Elektrochemie und angewandte physikalische Chemie. Generalregister, Bände 11–30. Jahrgang 1905–1924. Namenverzeichnis. 1927.

BOOK REVIEWS.

THE PROPERTIES OF SILICA. An Introduction to the Properties of Substances in the Solid Non-conducting State. By Robert B. Sosman, Ph.D., Geophysical Laboratory, Carnegie Institution, Washington, D. C. 855 pages, 8vo, illustrated. New York, The Chemical Catalog Company, Inc., 1927. Price, $12.50.

A compound to which Gmelin's "Chemistry" devotes less than four pages is given over eight hundred in this book and even this extensive treatment does not exhaust the topic, for such an interesting and important phase as silica gel is but passingly noted, since the object of the book as indicated in the subtitle is to deal with the really solid form. The book has indeed a wider scope than merely the treatment of the solid phase of SiO_2, being an introduction into the physics and physical chemistry of non-conducting solid substances.

Silicon has a wide function in nature. Belonging with carbon in the modern classification, it seems to be the fundamental element in the mineral world as carbon is in the organic. The analogy between them has naturally led to attempts to produce analogous compounds, and from the early days when Friedel and Crafts studied the esters of silicic acid to the present, many striking compounds in which silicon takes the place of carbon have been obtained. Among these is a series of hydrosilicon derivatives strictly comparable to the hydrocarbons, but mostly having the property of spontaneous inflammability. Silicon hydride (silicon methane) has long been known and has lately been applied as a smoke screen material. Crystallized silica in the native state is the substance that has given us the word "crystal," harking back to the idea of the Greeks that quartz crystals were produced by great cold.

The text of the book is largely devoted to the physical chemistry of solid silica. The varied and important optical properties are considered in much detail. Study of structure by the X-ray, which has proved so remarkable and useful in unraveling the intimate associations of the atoms of substances, is presented in full description and illustrated. The author makes a timely protest against the loose use of the term "quartz," pointing out that such phrases as "quartz mercury lamp," "quartz fiber" are not commensurate in meaning with "quartz spectrograph" or "quartz wedge." The former terms should be replaced by "vitreous silica," as the material is not quartz. He remarks that chemists and physicists have often ignored the protests of philologists and lexicographers in coining hybrids and monstrosities. He might have added that the same scientists frequently ignore the rules of grammar and syntax, writing such monstrosities as "data is" and "apparati."

The work is one of the series of monographs in course of publication for some years by the American Chemical Society, which has already furnished a large amount of excellent literature on special subjects. The information presented in the book is mostly from the investigations of the last twenty years, but as with many other specialized subjects, it is scattered through a vast amount of periodical literature. Meanwhile, a large amount of information in physical chemistry, bearing of course on many other substances than silica, but having also bearing thereon, has been developed and it was necessary to

incorporate the applications of all these data in the study of the substance in hand. It was, indeed, originally intended to include a study of silicates, but the necessity of presenting the bearings of the mass of new physical and physico-chemical information compelled restriction of the labor to silica alone, and even this compilation appeared much later than was expected.

The book contains a vast mass of information, carefully arranged and clearly set forth, and is one more of the many evidences that the volumes of this series have been indicating, namely, the high specialism that has developed in chemistry and the active research in the highest fields that is now carried on by American workers.

HENRY LEFFMANN.

THE PROPAGATION OF ELECTRIC CURRENTS IN TELEPHONE AND TELEGRAPH CONDUCTORS. By J. A. Fleming, M.A., D.Sc., F.R.S. Fourth edition, revised and extended. xv–422 pages, 14 × 22 cm., cloth. New York, D. Van Nostrand Company, Inc. Price, $8.

Very few of those who enjoy the advantages derived from latter-day advances in the transmission of electrical energy, either for power, signalling or for the transmission of sound, realize by how many years the modern theories which have made these amazing performances possible antedate their application. The work of Maxwell and then of Heaviside are the cornerstone of this modern structure, towards the completion of which Professor Pupin has so brilliantly contributed, by which obstacles which formerly defied solution have been overcome and the way opened to other and striking possibilities.

The object of this work has been to bring within the reach of telephonic and telegraphic engineers the most recent scientific and technical research which relates to their art. A perusal of the writings of Heaviside and of Professor Pupin, which have placed telephony on a sound theoretical and practical basis, as well as a study of the classical labors of Kelvin on submarine telegraphy, demands a type of mathematical training not usually attained by practical telegraphic and telephonic engineers. Professor Kennelly's writings have done much to meet this need. This matter, which deals with operations with complex quantities and hyperbolic functions, the author has presented very fully and comprehensibly in the first chapter, a valuable provision in view of the extensive application of these functions throughout the subsequent text.

The second chapter on the propagation of electromagnetic waves along wires is the keystone of the work in that it embraces the physical concepts of wave-motion, the deduction of a general expression for wave-motion and finally the derivation of differential equations expressing the propagation of an electromagnetic disturbance along a pair of wires. With the completion of this chapter, which will stress the reader's physico-mathematical capacity as much in visualizing the physical concepts employed as in following their mathematical treatment, the subject is fairly launched.

In the third chapter, we begin with the propagation of simple periodic electric currents in telephone cables under varying conditions of the line. Under "telephony and telephone cables" of the fourth chapter, an account is given of the nature of articulate speech, the derivation of Fourier's Theorem, the methods of achieving telephony over long distances and through submarine

cables, and a detailed explanation of the theory by Professor Pupin of unloaded and loaded cables. Chapter five, on the propagation of currents in submarine cables, covers the mathematical theory of modern submarine telegraphy. Much practical information is there given bearing upon the speed of signalling, which is discussed in mathematical language illustrated by diagrams. Chapter six deals with the transmission of high-frequency and very low-frequency currents along wires under varied conditions. An explanation of electrical measurements and the determination of the constants occupies the seventh chapter, with diagrams and illustrations of apparatus.

An engineering project is only complete when it has been checked. Chapter eight, in which cable calculations and comparison of theory with experiment are considered, dwells at considerable length upon the importance of such verification. "Loaded cables in practice" of chapter nine is a generous collection of data on the results attained from loaded cables. Of particular interest is the description, among others of note, of the New York-San Francisco telephone line, which exceeds all others in length. An inset diagram of this circuit is included. The tenth and last chapter on recent advances, which is an addition to the original work in this fourth edition, is a chronicle of recent progress. Among the achievements mentioned are: Improvements in the construction of loading coils, the extraordinarily high-permeability nickel-iron alloy, known as "permalloy," the vast improvement in telephony by the introduction of the thermionic repeater, of which the author is originator, and the development of carrier-wave multiple telephony. An appendix contains a table of the functions of hyperbolic angles.

By the issue of this work, Doctor Fleming has rendered a rare service to readers who are interested in problems of telephonic and telegraphic transmission in supplying in a form available to practical engineers a comprehensive account of the theory and practice of telegraph and telephone lines.

LUCIEN E. PICOLET.

MACHINISME ET AUTOMATISME. Par P. Maurer, Chef du Service des Compteurs, Ingénieur à la Compagnie Parisienne de Distribution d'Électricité, Professeur à l'École d'Électricité Bréguet et à l'École d'Électricité et de Mécanique industrielles. vi–80 pages, 23 × 14 cm., paper. Paris, Gauthier-Villars et Cie., 1927. Price, 12 francs.

There are many apparent enough economic reasons why, in no other part of the world which has experienced the rapid material progress of modern times, the individual has come into closer relation to a mechanized mode of life than in this country. Labor-saving machinery and labor-saving methods as well have found here the most fertile field for their development, and a multiplicity of mechanical devices that have become of commonplace application in our daily lives and indeed necessities to our creature-comfort or business routine, where different conditions prevail, might never have achieved the dominant estate which is now theirs.

Under the descriptive title "machinism and automatism," the author discusses first the philosophy of the subject. Having examined from several aspects what constitutes a machine, how human necessity has controlled its

evolution and, again, how procedure in manual operations has been meticulously analyzed to the great advantage of economy in production, and finally, how the general relations which govern the possibility or expediency of automatizing given mechanical operations, he proceeds to the more specific part of his discourse—the automatized machine.

In this part, the author describes how a science of machinism might be constructed upon the basis of a consideration of the distribution of energy in the functioning of a mechanism or the "energy function" as he terms it, and thence the possibility of deriving analytical expressions for pairs of energy-elements and finally the determination of a required member of that energy-chain which may be regarded analogous to the members of kinematic chains defined by Reuleaux. This unique method of attacking a problem which is usually considered wholly from a kinematic point of view is of unusual interest to investigators who aim to establish a rational theory of "genera and species" of machines.

LUCIEN E. PICOLET.

CHEMICAL PATENTS INDEX, Volume I. By Edward Chauncey Worden, First, Ph.C., B.S., M.A., F.C.S., F.L.S. 904 pages, 8vo. New York, The Chemical Catalog Company, Inc., 1927. Price, $25.

This comprehensive series representing an enormous amount of labor is to constitute five volumes, making an approximate total of little less than 4400 pages. It is an index of chemical patents issued through the United States Patent Office in the ten years from January 1, 1915, to December 31, 1924. The total cost of the work is set at $100, but this is to be paid at the rate of $25 on each volume until four volumes have been issued. The matter presented represents eleven years of uninterrupted labor of a small force, the intention being to cover in a satisfactory and comprehensive manner about 700,000 entries of chemical patents within the period above noted. The collection is intended to cover adequately the whole field of chemical technology, organic, inorganic, biologic, mineralogic, pharmaceutic and photographic, which includes really a survey of the entire activity within the ten years of applied chemistry both in peace and war. An index of patentees is given as the introductory matter and over 14,000 names are listed as sole or joint patentees. No attempt has been made to edit or correct the statements appearing in the patent index, each subject being presented as it is of record. This is important in the legal aspect, since courts have held practically that the validity and scope of a specification is to be judged by the actual statements and not by what might be inferred by experts. It is also a well-known principle of our patent law that the descriptions must be presented in such form as to be intelligible to those fairly familiar with the art to which the patent relates. There are in patents as recorded a great deal of involved phraseology, roundabout expressions and evidences of imperfect knowledge of chemistry or indeed little knowledge at all, so that very often an attempt to present the statements of the patents involves guesswork. In all such cases the editor has made a double entry, indexing the data as printed and then as he deduced what should be the correct reading. This, of course, has given rise to a great deal of detail and involved much extension of the index and sub-division of it.

The high refinement of the chemical and chemico-physical principles now concerned in industrial methods is shown by a paragraph in the preface which refers to "The present litigation in respect to the aryl-substituted guanidines as rubber vulcanization accelerators." In this field, as in so many others, an index of this type must be very extensive and comprehensive in order to facilitate searches for anticipations or lack of novelty, features which form so very important matters in patent litigation. The index has been prepared by taking a description of each patent as printed in the *Official Gazette* and if in any case it seemed to be of a nature of a chemical principle, the original document was obtained, from which could be indexed in detail the information concerning the chemicals, manipulations and mechanical devices sufficiently to cover apparently all of the strictly chemical information from any angle. These data were placed on cards, which were again reviewed. The preface describes in detail the methods of making this card index, but it is not necessary to go into a description of that. The Editor with the assistance of collaborators is now engaged in indexing patents for the ten years preceding the period to which this volume is devoted and also to two years succeeding. It is hoped to keep the work up to date by the issue of biennial volumes and if the labor and expense bestowed upon the work is met by satisfactory appreciation by the public, the investigation will be carried backward to the very earliest period of United States patents. The Editor very properly says that a complete collection of this kind would be a wonderful stimulus to patent inventiveness and ingenuity and would minimize useless litigation which is often based on faulty or inadequate information, particularly as to the fundamental character of patents allowed. One of the great difficulties in a list of this kind is the decision as to the practical indexing of the complex chemical terms now so familiar in organic chemistry. In the olden times this problem was simple, very few organic bodies were known except those existing naturally or derived by simple transformation from such natural products, but the development of organic synthesis has given us not only extremely long names, but very often two or three possible forms equally applicable. Thus alpha-aminonaphthalene is also alpha-naphthylamine; and benzoic acid is carboxybenzene. Hundreds of other instances might be cited. The system of indexing and expressing the composition of these complex substances is essentially that followed in *Chemical Abstracts*. The problem is still further increased by the fact that several systems of naming organic compounds have been developed in patent office methods, largely due to the fact that many patents are of foreign origin and the name system in other countries may be quite different from that used in standard American literature. The preface is very extensive, contains much information as to the methods of arranging the data in the work and finally gives credit to a number of collaborators who have assisted therein. The book was printed by the Lord Baltimore Press.

The index of subjects which in this first volume includes nearly eight hundred pages of closely but clearly printed entries, represents an enormous amount of very hard and really dreary labor and certainly American chemical industry must be thankful for this contribution. It is to be hoped that this thankfulness will be clearly expressed by a wide acceptance of the work and

its installation into all the libraries of corporations and scientific institutions interested in promoting the development of industrial chemistry in the United States.

HENRY LEFFMANN.

ANNUAL SURVEY OF AMERICAN CHEMISTRY. Volume 2, edited by Clarence J. West, National Research Council. 415 pages, small 8vo. New York, The Chemical Catalog Company, Inc., 1927. Price, $3.

It is gratifying to see how wide is the interest in chemical research in this country, and how active it has become. The present work reports American investigations carried out for one year from July 1, 1926. Forty-nine articles have been contributed, covering both theoretical and practical topics. Very thorough use has been made of the periodical literature and as each article has been prepared by an author especially interested, the usefulness of the book is assured. It will be found very serviceable to all chemists.

The reviewer suggests that in future volumes, the locality of every author should be noted. In many instances in the present issue merely a corporation with which the author is connected is indicated. Some interest is now manifested in the geographical distribution of intellectual activity in the United States, and an indication of locality would be of some value. So far as locality assignments are in the list, twenty-one contributors hail from four centres, New York, Washington, Baltimore and New Haven, seven being credited to each of the first two. Philadelphia has one contributor. It is also worth noting that notwithstanding the large opportunity given to women for instruction in the practical sciences, almost no part has yet been played by them.

There is a curious, though not infrequent, error, on page 289, in which "apparati" is used as a plural. The plural of "apparatus" is "apparatus." It is a masculine noun of the fourth declension, not of the second. "Persicos apparatus, odi puer." There are other indications of defective proof-reading on the part of authors. It is suggested that in future a classification be made of the papers which are now in rather confused mixture.

HENRY LEFFMANN.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS. Report No. 278, Lift, Drag, and Elevator Hinge Moments of Handley Page Control Surfaces, by R. H. Smith. 22 pages, illustrations, quarto. Washington, Government Printing Office, 1927. Price, ten cents.

This report combines the wind-tunnel results of tests on four control surface models made in the two wind-tunnels of the Navy aerodynamic laboratory, Washington Navy Yard, during the years 1922 and 1924, and submitted for publication to the Committee May 7, 1927. The purpose of the tests was to compare, first, the lifts and the aerodynamic efficiencies of the control surfaces from which their relative effectiveness as tail planes could be determined; then the elevator hinge moments upon which their relative ease of operation depended. The lift and drag forces on the control surface models were obtained for various stabilizer angles and elevator settings in the 8 by 8 foot tunnel by the writer in 1922; the corresponding hinge moments were found in the 4 by 4 foot tunnel by Mr. R. M. Bear in 1924.

PUBLICATIONS RECEIVED.

Annual Survey of American Chemistry. Volume II, July 1, 1926, to July 1, 1927. Edited by Clarence J. West. Published for the National Research Council. 415 pages, 12mo. New York, The Chemical Catalog Company, Inc., 1927. Price, $3.

Chemical Patents Index. A comprehensive and detailed index of the subject-matter of specifications and claims of United States patents and patent reissues granted during the decennial period 1915–1924 inclusive, covering the entire field of chemical technology, by Edward Chauncey Worden, First. 904 pages, 8vo. To be complete in four volumes. Price, $100. Single volumes cannot be purchased, subscriptions for the set may now be made. New York, The Chemical Catalog Company, Inc., 1927.

Cours d'Électricité Théorique professé à l'École Professionelle Superieure des Postes et Télégraphes, par J. B. Pomey. Tome II. 373 pages, illustrations, 8vo. Paris, Gauthier-Villars et Cie., 1928. Price, 100 francs.

The Properties of Silica. An introduction to the properties of substances in the solid non-conducting state, by Robert B. Sosman, Ph.D. 855 pages, illustrations, 8vo. New York, The Chemical Catalog Company, Inc., 1927. Price, $12.50.

Les Turbines a Vapeur. Traité a l'usage des ingénieurs, des techniciens et des élèves ingénieurs des écoles d'application, par Ing. Giuseppe Belluzzo. Traduit de l'Italien, par Jean Chevrier. Second edition, entirely rewritten. Two volumes, illustrations, 8vo. Paris, Gauthier-Villars et Cie., 1927. Price, 140 francs.

Thermionic Phenomena, by Eugène Bloch, translated by J. R. Clarke. 145 pages, illustrations, 12mo. New York, E. P. Dutton and Company, no date. Price, $2.50.

Scientific Paradoxes and Problems and Their Solutions Simultaneously Broadcast from 2LO, by A. S. E. Ackermann, with an introduction by Prof. C. V. Boys, F.R.S. 131 pages, 12mo. London, The Old Westminster Press, 1925. Price, five shillings.

Physics in Industry. Lectures delivered before the Institute of Physics, by H. E. Wimperis and F. E. Smith. Volume 5, 54 pages, illustrations, plates, 8vo. London, Oxford University Press, 1927. Price, two shillings, six pence.

Wireless Direction Finding and Directional Reception, by R. Keen. Second and enlarged edition. 490 pages, illustrations, 8vo. London, Iliffe and Sons, Limited, 1927. Price, 21 shillings.

Encyclopédie Photométrique. Première section—Généralités. I. Introduction Générale à la Photometrie, par Charles Fabry. 178 pages, illustrations, 8vo. Price, in paper, 20 francs.

National Advisory Committee for Aeronautics: Technical Notes, No. 270. The Characteristics of the N.A.C.A. 97, Clark Y, and N.A.C.A.-M6 Airfoils with Particular Reference to the Angle of Attack, by George J. Higgins. 4 pages, diagrams, quarto. Washington, Committee, 1927. Thirteenth Annual Report of the National Advisory Committee for Aeronautics, 1927. Administrative report without technical reports. 76 pages, portrait, quarto. Washington, Government Printing Office, 1927. Price, twenty cents.

CURRENT TOPICS.

The Measurement of True Specific Heats at High Temperatures by Heating through Electron Bombardment. H. KLINKHARDT. (*Ann. der Physik,* **84,** No. 1.)—For low and for medium temperatures it has been possible to find specific heats with accuracy but for high temperatures a solution has been lacking. In a preliminary article appearing in 1926 a method was described in which energy was conveyed to the body whose specific heat was desired by bombarding it with slow cathode rays in a vacuum. This way of applying energy had been previously used qualitatively to drive off gases and to produce fusion in a vacuum, but quantitatively it seems to have been employed only to determine the heat of evaporation of certain metals and in that case with but little success. In general the following is the arrangement. In a high vacuum the body whose specific heat is to be measured is made an anode in front of a source of electrons. From the quantity of electricity reaching the experimental body and the number of volts through which it falls the contributed energy is calculated. The rise of temperature is gotten by a thermo-element. The temperature at which the experiment is conducted is governed by an auxiliary heating coil.

Whatever X-rays are produced by the electrons in striking the anode are negligible since their energy is very small. The electrons upon leaving their source, a hot cathode, have a calculable amount of thermal energy. Further, when the impinging particles are incorporated with the anode there is a setting free of potential energy.

During the experiment a MacLeod gauge showed generally a pressure of about 1 to 5×10^{-5} mm. mercury. The fall of potential of the bombarding electrons did not exceed 300 volts.

For copper the values of the specific heat rose from .0947 at 100° to .1120 at 800° C. They are given at intervals of 100°. With lead determinations were made both below and above the melting-point, 327°. Most of the observations below the melting-point were made on ordinary lead while pure metal was used for the liquid. At 50° the specific heat was .0312 and at 327° .0362 for the solid state and .0388 for the liquid. In the case of the solid ordinary lead from 300° onward the specific heat increased considerably, thus indicating that the process of melting was spread over an interval as is true for alloys to which this not chemically pure lead belonged. On the contrary the pure lead showed no departure from its regular course as it was heated up toward the melting-point, even when the temperature intervals at which the specific heat was measured were reduced to as little as .3°. At the melting-point there was a sudden jump of 7 per cent. in this quantity. From .0388 at 327° it descended to a minimum of .0367 at 435° and at 500° became .0370. The heat

of fusion of lead was also determined and found to be 5.65 cal./gr. The sensitiveness of the method is evidenced by the results just cited.

Only about 1 c.c. of tin was used in the experiments to see whether the method could be employed for so small a mass of metal. The results were poor. With ammonium chloride, a poor conductor of heat, sealed in a container of copper foil, the method worked well. At 184.5° the substance underwent a modification which manifested itself by a sharp drop in the value of its specific heat.

The specific heat of solid iron rose from .1150 at 100° to .2300 at 700°, the rate of increase becoming greater per 100° as the melting-point was approached, but dropping with striking rapidity from .3200 at 760° to .2095 at 800°. The significance of 760° is that it was the A_2 point, or Curie point, for the iron used, the temperature at which iron loses its ferromagnetism. Iron has still another temperature of transformation below 1000°, the A_3 point at about 906°. "The specific heat began to increase at 904°, passed through a very high maximum at 908° and reached the normal value again at 911°."

Like iron, nickel has a maximum value for its specific heat at its Curie point, which was at 360°, after which a rapid decrease occurs. This is followed at higher temperatures by an increase.

This new method is especially valuable for its fitness to trace changes in specific heat at melting and transformation points.

G. F. S.

The World's Water Power.—The extent of the industrial development of a nation, which is the modern measure of its civilization, can probably be gauged best by the extent of its use of mechanical energy. For this reason it is interesting to compare the extent to which the water-power resources of various countries have been utilized and the progress which is being made in building new plants. In both respects, according to an estimate made by the Department of the Interior through the Geological Survey, the United States leads all other countries of the world, and in the capacity of its constructed plants it nearly equals all Europe. The total for the United States at the end of 1926 was 11,700,000 horsepower for plants of 100 horsepower or more, as against 13,100,000 horsepower in Europe, presumably for plants of all sizes. In the six-year period 1921 to 1926 the capacity of constructed plants in the United States of 100 horsepower or more increased 3,800,000 horsepower, while in Europe the increase in plants of all sizes was 4,200,000 horsepower. During the last three years of that period, however, the rate of increase in the United States was much greater than during the first three years, whereas the rate of increase in Europe showed a decline. The leading countries in Europe in the use of water power and the capacity in horsepower of their constructed plants in 1926 are as follows: Italy, 2,300,000; France, 2,000,000; Norway, 1,900,000; Switzerland, 1,850,000; Sweden, 1,350,000.

The developed water power of Africa amounts to only about 14,000 horsepower, but Japan has built plants aggregating 1,750,000 horsepower, and India 200,000 horsepower. New Zealand has some large plants under construction, but those completed have a capacity of 60,000 horsepower. The Dutch Islands of Java, Sumatra, and Celebes have plants of 80,000 horsepower. Tasmania's plants have a capacity of 75,000 horsepower. Australia depends mostly on fuel plants and has utilized only 2000 horsepower of its water-power resources.

In South America, Brazil leads the other countries by a wide margin, with 500,000 horsepower, most of it used in Rio de Janeiro and Sao Paulo. Chile's plants amount to 114,000 horsepower, and Peru's to 55,000 horsepower.

Coming back to North America, we find that Mexico has plants with a capacity of 300,000 horsepower. A large part of this capacity is in plants supplying Mexico City and there is not much activity in building new plants. Newfoundland has a large new plant for the manufacture of paper that increases its total to 160,000 horsepower. But the only real competitor of the United States in the whole world is our neighbor, Canada, whose plants had a total capacity of 4,556,000 horsepower at the end of 1926, an increase of 2,138,000 horsepower since 1920.

At the end of 1926 the developed water power of the world was as follows: North America, 16,800,000 horsepower; South America, 750,000; Europe, 13,100,000; Asia, 2,100,000; Africa, 14,000; Oceanica, 240,000; total of 33,000,000. As the total capacity of the water-power plants of the world in 1920 was 23,000,000 horsepower, there was an increase of 43 per cent. in the six years.

Ultra-violet Rays of Sunlight.—LEONARD HILL (*Proc. Royal Soc.*, London, 1927, B, 102, 119–128) has measured the biologically active ultra-violet rays of sunlight. He finds that a great loss of this radiation occurs in smoky cities. Less of this radiation reaches the surface of the earth in winter than in summer. A greater amount of these rays was received at Davos, Switzerland, than at the most favored British place, while Assouan in Egypt received a still greater amount than Davos. J. S. H.

Mold in Butter.—H. MACY and W. B. COMBS (*University of Minnesota Agricultural Experiment Station Bull. 235*, 1927, 1–31) have made a field study of the sources of mold in butter at sixteen creameries. They find that the chief sources of mold are the raw milk and cream, and the creamery equipment, such as pipes, pumps, and churns. Other possible sources are the water, the starter, the salt, and the parchment paper. Practically all the sources may be eliminated by thorough pasteurization of the cream and thorough sanitation in the creamery. J. S. H.

Two Adverse Conceptions of the Nature of Light and Their Synthesis. LOUIS DE BROGLIE. (*Scientia*, 1, ix, 1927.)—Jules Tannery has made the profound observation that from the beginning of thought human beings have divided themselves into two groups. The one everywhere finds and seeks for continuity, while the other seeks and finds discontinuity. In mathematics these opposing tendencies are illustrated by the study of discontinuous numbers on the one hand, and of continuous functions on the other. In physics discontinuous conceptions are such as the atomic theory of matter and the kinetic theory of gases, while the optical theory of Fresnel and the electromagnetic theory of Maxwell belong to the opposite aspect.

In the study of dynamics from the seventeenth century onward the two points of view have shown themselves. On the one side we have the dynamics of particles and of assemblages of particles, and on the other the dynamics of continuous media. Yet the two views have by no means maintained entire isolation. In hydrodynamics, for example, the prevalent conceptions of continuity are not objectionable to the most convinced atomist because he understands the density and other properties of liquids as statistically representing on the scale of human perception the resultant of actions of the particles in which he believes. In the motion of a material particle in a field of force the governing relation is this, mass × acceleration = force. The very introduction of such a concept as force, which varies from point to point, is a concession to continuity, and is fundamentally an admission that the motion of the particle depends on a property of the space surrounding it. "We see then that in the domain of dynamics the two great tendencies of our minds have had free course and that they have been obliged to make mutual concessions. Here, as in many other fields, progress has been established by the equilibrium between opposing tendencies."

In optics the same conflict is seen. Lucretius held that light consists of particles in motion. Huyghens advanced the wave theory of light. Newton lent the weight of his genius to the support of the corpuscular theory and his were the prevalent conceptions up to the beginning of the nineteenth century when Young and Fresnel turned the scale to the other side and made the scientific world believe the undulatory theory. Maxwell later changed the meaning of this theory but left its large features untouched so that down to the advent of the theory of relativity men had confidence in the existence of a continuous medium that transmitted the vibrations causing the sensation of light.

While the theory of a continuous ether was establishing itself in physics the discontinuous theory of atoms was gaining an equally signal victory in chemistry, a victory extended to the territory of physics by the success of the kinetic theory of gases, and by Perrin's work on Brownian movements. Then the idea of atomicity was applied to electricity and the electron seems to have become permanently established. Lorentz recast electrical theory so as to make

it hospitable both to the electron and to Maxwell's theory of continuity. "Here again we see the same two fundamental tendencies compelled to make concessions one to the other, the partisan of discontinuity being constrained to admit the representation of the electromagnetic field by continuous functions while the advocate of continuity had to adjust himself to the existence of elementary particles of electricity."

About the beginning of the present century Planck presented his strange conception, the quantum. In the radiation of a black body classical views led to a law of the distribution of energy that varied from observed facts. To get a reconciliation of theory with experiment the German physicist made the following postulate, "Exchanges of energy between matter and radiation having a frequency of ν cannot take place except in finite quantities equal to $h\nu$, h being a new universal physical constant." The quantum theory has many successes to its credit. Its train of victories makes clear two conclusions: (1) The former theory of the dynamics of a material particle was incomplete because it led to a wrong deduction. (2) The conception of radiation as a continuous phenomenon is likewise lacking, because radiant energy is admitted and absorbed by quanta. The first conclusion is strengthened by the valuable results obtained by Bohr from applying the quantum theory to atomic mechanics.

In the present century it is the photo-electric effect that has done most to change our ideas of the nature of light. Matter under the influence of light ejects electrons whose kinetic energy depends not on the intensity of the incident light, but upon its frequency. Einstein in 1905 applied the conception of the quantum to this phenomenon and derived a numerical relation that has found wide experimental verification. The hypothesis of light quanta means a return to the ideas of Newton. Its acceptance to the exclusion of the undulatory theory would bring with it the impossibility of explaining diffraction. The discovery of a new effect made by A. H. Compton in 1923 went far to confirm belief in the quantum theory. He found that a part of the X-radiation falling upon matter is lowered in frequency by being diffused. This is explained as follows: A quantum of light impinges on an electron. The result is that the quantum subsequently has less energy and a smaller frequency. The theory developed at the same time by Compton and by Debye has been found to agree quantitatively with experimental results.

We have thus on the one hand such luminous phenomena as interference and diffraction and on the other the Compton effect and the facts of photo-electricity. The wave theory of light explains the first group of experimental results and the quantum theory the second. Is there no possibility of a theory applicable to both sets of phenomena? In the opinion of the author "a material point can no longer be regarded as an isolated unit but rather as the centre of an extended undulatory phenomenon inside of which it forms a singularity. The quantum of light must also be a material point,

no doubt of a particular nature, yet not essentially different from other similar particles. It likewise is a singularity within the wave and the laws of wave propagation determine the movement of this singularity." Dynamics has hitherto given all its attention to the singularity and neglected the accompanying wave. Its results have been correct in most cases but not correct when it is impossible to leave out of account everything but the singularity. The classical theory of optics has fixed attention on the wave and disregarded the singularity within. The synthesis of the two points of view with which the names of De Broglie and Schrödinger are connected has already had considerable success. "In the series of successive approximations by which Science is constructed a new stage seems to have been reached."

On the first page of *Le Matin* (Paris) for November 17, 1927, and in the first column of the page, Charles Nordmann discusses De Broglie's theory. What shall be thought of a newspaper that gives its most prominent space, not to murders and scandals, but to abstract scientific theory? G. F. S.

The Magnetic Susceptibility of Some Binary Alloys. J. F. SPENCER and MISS M. E. JOHN. (*Proc. Roy. Soc.*, A773.)—When Heusler produced alloys that belonged to the ferromagnetic class of substances along with iron, cobalt and nickel, by melting three metals together, no one of which by itself belonged to that class, he added one more problem to the many already waiting for solution in the field of magnetism. This paper presents still other strange magnetic results. "The object of this research has been to find a connection between the mass susceptibility and chemical composition of a number of binary alloys of several metals." The mass susceptibility is found by dividing the magnetic moment per gram developed in a substance placed in a magnetic field by the strength of the field. Measurements of the susceptibility were made with a Curie and Cheneveau magnetic balance in which the field of the permanent magnet had a strength of 640 gauss.

"The binary alloys of gold with lead, tin and cadmium, lead with silver, tin and bismuth, and tin with aluminum and cadmium have been examined over the whole range of compositions. The metals from which these alloys were prepared were the purest obtainable. Each metal was analyzed before use, particular care being taken to ascertain that iron was not present in appreciable quantity." The constituent metals were melted together in an electrically heated crucible and the resulting alloy was cast into a rod. From this was cut the test-piece, and adjacent portions of the rod on each side of the test-piece were analyzed. This was worked into a cylinder of .36 cm. diameter and .65 cm. length. "It was then washed in hydrochloric acid to remove possible traces of iron which may have become attached to it during the trimming. The washing was repeated until a constant value was obtained for the susceptibility."

The following values were found for a million times the mass susceptibility of the pure metals, temperatures being confined to the range from 18° to 20.5°: Silver, −0.201; lead, −0.119; cadmium, −0.156; tin, +0.044; gold, −0.118; aluminum, +0.583; bismuth, −1.24. Note that with the exception of tin and aluminum all the metals used were diamagnetic.

Silver-Lead Alloys.—Since both of these metals are diamagnetic and have values of the mass susceptibility lying close together, it might well be expected that their alloys would all be diamagnetic and to about the same extent as the two constituent metals. However, when alloys containing a small proportion of silver were tested it was discovered that the addition of this metal did not cause the susceptibility to approach that of silver but, on the contrary, made it have a smaller negative value than that of lead. As alloys with more and more silver content were made and examined, it became clear that this slight change continued in the same direction until about 40 per cent. by weight of the alloy was silver. Then with further increase in the proportion of silver the susceptibility rapidly increased, becoming zero for 45 per cent. of this metal. The meaning is that the alloy containing 55 per cent. lead and 45 per cent. silver is non-magnetic. Alloys with percentages of silver in excess of 45 have a positive susceptibility, that is, they are paramagnetic in character. The maximum positive value of the susceptibility is 2.03 and is for an alloy containing 70.8 per cent. silver. For alloys with still greater silver content the susceptibility rapidly falls, becomes zero for 99.1 per cent. silver (where the alloy is again non-magnetic) and finally as the alloy ceases to contain any lead is once more negative. We have here a series of alloys of two diamagnetic metals that never shows as strong a diamagnetic character as silver alone, so long as any lead whatever is present, and that is actually paramagnetic for nearly half of the possible alloys made from the two metals.

Gold-Lead Alloys.—These are quite as anomalous as those just considered but in a different way. Let it be noted that gold and lead have almost exactly the same susceptibilities. In spite of this the addition of 6 per cent. gold causes the negative value of the susceptibility to become nine times as great as that of either constituent. Alloys richer in gold are less strongly diamagnetic until for gold contents of 38 per cent. and 44 per cent. the respective alloys are non-magnetic. Alloys between these two limits are paramagnetic in nature, though only feebly so.

Gold-Tin Alloys.—"The addition of a small amount of gold to tin yields a diamagnetic alloy; the curve crosses the zero-susceptibility line at about 6 per cent. of gold and does not reënter the paramagnetic region at any point of its course." All gold-cadmium alloys have small susceptibilities. There are no less than four alloys which are non-magnetic. Both aluminum and tin are paramagnetic, yet nearly all of their alloys are diamagnetic. For the alloy contain-

ing 76 per cent. of tin the value of the susceptibility is almost as great as for bismuth. Two alloys are non-magnetic. There is only one bismuth-tin alloy that is non-magnetic. Moreover there is but one non-magnetic cadmium-tin alloy and likewise one lead-tin alloy. The lead-tin alloys are the only ones examined that show regularity. "The susceptibility falls fairly regularly from the value of pure tin to that of pure lead." G. F. S.

Infra-red Radiation of Hydrogen. A. H. POETKER. (*Phys. Rev.*, Oct., 1927.)—In 1885 Balmer discovered that the wave-lengths of the longest-known hydrogen lines, H_α, H_β, H_γ, and H_δ, are connected by simple numerical relations and can be calculated by substituting small whole numbers for letters in a formula. This relation is now understood because these lines are due to transitions of electrons to the two-quantum end state. Lyman in 1914 detected in the ultra-violet the series of lines due to transition to the one-quantum normal state, and Paschen in 1909 found two lines in the infra-red belonging to the transition of electrons from outer orbits to the third stable orbit. The formula for this series is $\frac{1}{\lambda} = 109{,}677.7 \left(\frac{1}{3^2} \frac{1}{n^2}\right)$, where λ is the wave-length of the lines of the series. The wave-length of the line farthest from the visible spectrum is calculated by substituting 4 for n in the above equation. For the next line 5 replaces n and so on. A few years ago Brackett was able to identify three more members of the Paschen series, but his method of investigation did not permit accurate measurement of their wave-lengths. Poetker has succeeded in photographing six higher members of the Paschen series, for which n has the values from 6 to 11, inclusive.

The tube containing the hydrogen from which the light was emitted was about two metres long in the shape of an inverted U. The gas was supplied continuously to the tube, which was also exhausted continuously. A 6900-volt, 5-kilowatt transformer excited the tube. By adjustment of pressure and current density the "black" stage was maintained in the tube. The radiation from most of the tube then consisted of nothing but Balmer lines. Light was taken end-on from the tube and dispersed by a plane grating with 15,000 lines to the inch. The photographic plates used were the neocyanin plates recently made by the Eastman Company. These were hypersensitized just before use. With long exposure to strong radiation these plates have recorded the mercury line of length 11,288 Å.U. Even with long exposure the photographic record was very faint, but the author characterizes them as "unmistakable." Owing to the width of slit used and to the weakness of the lines there may have been, it is said, an error of as much as 1 Å.U. (.00000001

cm.) in the measurements of the wave-length. The following table allows us to compare the measured values of the wave-lengths with those derived from the formula given above.

Line.	Observed in Air.	Calculated Value.
P_α	18,751.3 (Paschen)	18,751.4
P_β	12,817.6 (Paschen)	12,818.3
P_γ	Not measured (Brackett 1.09μ)	10,938.2
P_δ	10,049.8	10,049.5
P_ε	9,546.2	9,546.0
P_ζ	9,229.7	9,229.1
P_η	9,015.3	9,014.9
P_θ	8,863.4	8,862.9

In no case do the observed and calculated values differ by as much as one Ångström unit.

In the course of the experiments a vigorous secondary spectrum manifested itself, on which little had been published. This was photographed. Four hundred and twenty-five lines were measured, ranging in length from 10,654.5 to 7504.5 Å.U. These are members of the molecular spectrum of hydrogen. G. F. S.

The Diffraction of Light at Steel Edges. F. JENTZSCH. (*Ann. der Phys.*, **84**, No. 2.)—About forty years ago Gouy and W. Wien showed that light becomes polarized by being diffracted about a metallic edge and that a considerable change of phase occurs when the angle of diffraction is large. In this paper the test of experiment is applied to the theories which Epstein and Sommerfeld have advanced to account for the observed phenomena. That of Epstein agrees better with the facts though neither one shows more than a qualitative accord. Since Epstein's formula is applicable only for values of the radius of curvature of the edge that lie near $1/6\mu$ ($\mu = .001$ mm.), attention is directed to the geometrical constants of the diffracting margin. Accordingly the author puts at the head of a section of his paper the question, "How sharp is a razor blade?" Reproductions of photographs are given, showing the edges of microtome blades with 800-fold magnification. They are uneven and saw-like, the precise nature of the irregularities depending upon the method of sharpening. The resulting edge is much more saw-like when the direction of motion of the blade over the hone makes an angle of 45° with the line of the blade than when this angle is small. One razor blade showed only small departures from linearity even under 1000-fold magnification. Methods of whetting blades that tend to make them free of inequalities do not produce the sharpest cutting edges. A blade without tiny saw-teeth does not cut as well as one having them. In addition to the projections resembling saw-teeth the line of the edge has the defect of being generally wavy in a plane perpendicular to the blade. To sharpen a blade means to remove this wavy contour, since the presence of little saw-teeth is not a hindrance to cutting. Continuing too long to sharpen a blade

may result in making it duller by reason of removing the saw-teeth. The linearity of excellent blades was examined under 1200-fold dimensional magnification. The cutting edge then appeared to consist of a line of bright points. Two pictures show departure from a straight line though, of course, to but a small extent.

A method for measuring the thickness of the blade near its cutting edge was devised with the use of the microscope. This showed that the sides of the blades are not planes. The radius of curvature of the edge seemed to be from 1 to 2μ.

It is quite clear that the irregularities of the limiting edge would reflect once or more a part of the beam of light used in the study of diffraction. Thus there would be superimposed upon regular diffraction certain effects for which allowance cannot be made. Search was therefore made among crystals for edges beyond reproach but in vain. Equally without result was the endeavor to avoid the difficulty by other means, so that up to the present there seems to be no means of getting a geometrically satisfactory edge for the study of diffraction. G. F. S.

The Use of Radio-elements as Indicators. FRITZ PANETH. (*Nature*, December 17, 1927.)—For the past generation radio-active substances have received so much attention and so much research has been devoted to them that it seems only fair that they should in turn make a contribution to the number of general methods of investigation. Their use as indicators is facilitated by the fact that by the movements of an electroscope it is possible to detect and even to measure exceedingly small quantities of radio-active matter. "From the radio-element thorium C, for example, which can very frequently be used as an indicator, 10^{-17} gm. allows for exact qualitative and quantitative determination."

It is the electrical charge on the nucleus of an element that determines its chemical properties. This charge is found by subtracting the sum of the negative charges on the electrons in the nucleus from the sum of the positive charges upon the protons here located. The same excess of positive charge can, of course, exist on very differently constituted nuclei which possess different masses and consequently also different atomic weights. These isotopes, possessing different atomic weights but the same nuclear positive charge and the same number of planetary electrons, can be separated only by means of those properties that depend upon differences in their nuclei. Since their nuclear charges are the same they cannot be separated by chemical means but, since their atomic weights are not the same, velocity of evaporation should vary from one isotope to another. Indeed, by this means two varieties of mercury of slightly different densities have been prepared. In the use of radio-elements as indicators a small quantity of a radio-active element is added to a considerable quantity of an inactive element isotopic with it. The two will go through all chemical processes together but only the radio-active constituent will affect the electroscope. It is something

like banding a few birds in order to study the migratory habits of the whole species.

In making choice of a radio-element to serve as an indicator, preference would naturally be given to one that can be detected in small quantities, that is, to one with intense emission, but it is just such a one that dies away with rapidity, *i.e.*, that has a small half-value period. This consideration rules out the employment of thorium C′, half of which is transformed in 10^{-11} sec. The author gives a list of all available radio-elements with an indication of the best for use as indicators.

The vanishingly small solubility of lead chromate at room temperatures can be measured with little labor with a radio-active indicator. Active thorium B is added to a soluble lead salt. From the mixture the chromates of the two constituents are prepared by the usual chemical methods. A small volume of the saturated solution of these salts is evaporated to dryness and the radio-activity of the microscopic residue is measured by the electroscope. From the quantity of the radio-active chromate found is inferred the mass of the inactive salt.

"Proof of the actual fact of dissociation, and of the interchange of ions, is readily obtainable with the help of the radio-elements, mixed, in accordance with the procedure just outlined, with their inactive isotopes. It is possible to demonstrate in this way the fact that the particular atoms or radicals assumed to be liberated by electrolytic dissociation do not retain their places in given molecules, but are free to move back and forth from one place to another. If, for example, equimolecular amounts of an inactive lead chloride and a radiochemically sensitized lead nitrate in aqueous solutions are mixed together, and the lead chloride is allowed to crystallize again, it will be found that the active lead atoms are distributed proportionally between chloride and nitrate, and must therefore have migrated in solution from lead nitrate to lead chloride until the kinetic equilibrium has been established."

During the war radio-elements found application as indicators in the testing of the permeability of rubberized fabrics to gases. A trace of radium emanation was added to the gas used. The storing up and elimination of bismuth in the organs of guinea-pigs has been studied by adding to the salt of this element some radium E which is isotopic with it. The self-diffusion of lead into lead has been measured by Hevesy. He sealed up in a glass tube a cylinder of lead composed for three-fourths of its length of ordinary lead and for the remaining length of lead activated with thorium B or, for lengthy experiments, with radium D. The cylinder was carefully melted and maintained at a definite temperature for several days. After solidification had been permitted analysis of the different portions of the cylinder made it possible to calculate the rate at which the "marked lead atoms had diffused into the others."

G. F. S.

The Height at Which Large Meteors Appear and Disappear. ALFRED WEGENER. (*Meteorologische Z.*, August, 1927.)—The phenomena of meteors can provide valuable information concerning the regions of the atmosphere that lie more than 30 kilometres above the surface of the earth. Though somewhat remote this portion of the earth's envelope is of importance on account of its influence upon the transmission both of electrical and of sound waves. Lindemann and Dobson a few years ago made a study of the elevations at which shooting stars finally disappeared after completing their luminous course. They tabulated the numbers of these bodies disappearing at different heights. The distribution is not the same for summer as for winter. In both seasons the number disappearing grows larger as heights farther and farther above 25 or 30 km. are considered until a maximum is attained at 45 km. For greater heights the number disappearing dwindles until at about 65 km. a minimum is reached. For still greater elevations there is a sharp increase in the number until in summer the greatest number disappears at a height of 85 km. and in winter at 75 km. Very many more shooting stars cease to be seen at these high maximum points than at the level of 45 km.

Wegener thought it to be of interest to make a similar examination of the heights at which larger meteors, such as fire-balls and detonating meteors, make their appearance and subsequently disappear. Fortunately there was ready at hand a catalog of data for 611 large meteors. Such bodies are visible for approximately 10 sec. Hence their speeds are obtainable with considerable accuracy. Against the geocentric velocities in steps of 10 km. are arranged mean heights of appearance and of disappearance along with the number of meteors for each velocity. The velocities range from 0 to 110 km. per sec. As would be expected, the greater the speed, the higher the level at which they appear and also disappear. For the disappearance from view of the meteors under examination the elevation of 47 km. has some special significance, because "at this height disappear not only the meteors with speeds of from 40 to 50 km./sec. but also all with lower velocities down to the range of from 10 to 20 km./sec., whose termination would be expected at lower levels. In other words, at 47 km. some obstacle seems to exist." About 70 per cent. of all the meteors tabulated finished their visible courses near the height of 47 km.

A study of the number of large meteors appearing at different levels and of the number disappearing at various levels shows that "most often the luminous paths begin at about 100 km. above the earth and end at 30–40 km." The same two maxima occur in the frequency-elevation of disappearance curve as was observed by Lindemann and Dobson, but their relative importance is reversed.

G. F. S.

John Richardson Young, a Pioneer Physiological Chemist in America.—WILLIAM FOSTER, of Princeton University (*Jour. Chem. Education*, 1927, 4, 1499–1504), describes the pioneer work of John

Richardson Young on the chemistry of digestion. Young was born at Hagerstown, Maryland, about 1782, was educated in arts at the College of New Jersey, now Princeton University, from which he graduated in 1799, and in medicine at the University of Pennsylvania, from which he graduated as a Doctor of Medicine in 1803. His doctoral thesis was entitled "An Experimental Inquiry into the Principles of Nutrition and the Digestive Processes." Among his teachers were Benjamin Rush and James Woodhouse. His research was made on laboratory animals, such as frogs, snakes, and lizards, and on human beings. Study was made of the processes of digestion in the stomach of the common large bull-frog, removing the gastric contents for observation at intervals of time. Digestion in the human stomach was studied by examination of gastric contents regurgitated a definite time after ingestion of a test meal. He also obtained pure gastric juice, and studied its action on substrates *in vitro*. Young recognized the presence of an acid in the gastric secretion, but erroneously thought it to be phosphoric acid; he also demonstrated that acid gastric juice prevented putrefaction. This pioneer American physiological chemist died at Hagerstown on June 8, 1804, in the twenty-second year of his age. J. S. H.

Domestic Use of Electric Power. (Department of the Interior, Press Memorandum.)—The estimated output of nearly 80,000,000,000 kilowatt-hours of electric power for the United States in 1927, if it could be converted into equivalent man power, would provide the average family of about four persons in the United States with the services of eleven able-bodied mechanical laborers working eight hours daily, including Sundays and holidays, at a total cost for the eleven of about $75 a year.

The total production of electricity by public-utility power plants in 1927 is estimated by the Department of the Interior, through the Geological Survey, at about 79,700,000,000 kilowatt-hours, an increase of about 8 per cent. over the output for 1926, which was 73,791,000,000 kilowatt-hours. The estimate for 1927 is based on reports of monthly output of electricity by public-utility power plants for the eleven months, January to November, and estimated figures of output for December. The latest monthly report, released January 4th, contains the figures of monthly output for September, October, and November.

Tuberculosis.—LOUIS I. DUBLIN and GEORGE H. VAN BUREN (*Tubercle*, 1927, **9**, 22–31) discuss the declining death-rate from tuberculosis in the United States. Of the twenty states included in the registration area in 1910, each has shown a large decrease in the number of deaths from tuberculosis per 100,000 of population. This decrease has been practically continuous at each five-year period; thus the rate in Pennsylvania has been: 133.8 in 1910; 129.2 in 1915; 105.0 in 1920, and 77.0 in 1925. The decrease has been much

greater in the urban than in the rural areas of the country. The reduction in the tuberculosis death-rate has extended to both the white and the colored races, but has been less pronounced among colored people than among Caucasians. These results are attributed to health education, and improved hygienic conditions in the home and in the industries. Evidence exists that tuberculosis must either ultimately disappear or become a relatively rare disease.

J. S. H.

Use of Protective Colloid with Nessler Solution.—H. M. CHILES (*Jour. Am. Chem. Soc.*, 1928, **50**, 217–221) recommends the use of an ammonia-free aqueous solution of gum arabic as a protective colloid to prevent the precipitation of the colored compound by inorganic salts when Nessler solution is added in the colorimetric determination of nitrogen. The gum arabic solution contains 5 per cent. of that gum and is rendered ammonia-free by means of Permutit; it is used in the ratio of 3 c.c. for each 5 c.c. of Nessler solution. The ammonia solution—standard or unknown (*e.g.*, solution from Kjeldahl digestion)—is neutralized prior to addition of the protective colloid and the Nessler solution.

J. S. H.

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